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ORIGINAL ARTICLES.

Foraminifera from some Late Pliocene and Glacial Deposits of East Anglia.

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(PLATES XXXIV AND XXXV.)

SUMMARY.

ELEVEN out of twelve samples of East Anglian Uppermost Pliocene and Pleistocene crag, clays, boulder clays, brickearths, and sands yielded foraminiferal faunas which are partly derived from older deposits. One hundred and thirty-one species are recorded, with their distribution in the samples and frequency; thirty-nine are indigenous, one derived from the Lower Pliocene, fifty-eight derived from the Chalk, eighteen derived from the Jurassic, and sixteen of doubtful age. Twenty-seven forms, largely indigenous, are figured; none are new. Notes are given on a few of the species. A short discussion, based solely on the foraminifera, is given of the climatic conditions under which the various deposits were laid down. The Weybourn Crag fauna points to cold conditions, and that of the Chillesford Beds sample to a climate rather less cold. From conflicting evidence and the derived nature of the faunas no very precise conclusions are possible in the case of the Pleistocene deposits, since the faunas contain a sprinkling of species characteristic of temperate or even warm conditions in addition to typically boreal forms.

INTRODUCTION.

During the British Association geological excursion to East Anglia in September, 1931, specimens of late Pliocene and Glacial deposits were collected to wash for foraminifera. The results show that there is generally a fauna to be obtained and, as published work on the foraminifera of these particular deposits appears to be almost lacking, it may be of value to put the results of the present investigation on record. The additional evidence may be useful to geologists as a fresh aid in unravelling the somewhat involved stratigraphical relations of the late deposits of East Anglia. Whilst the smaller foraminifera have points in common with heavy minerals, they have, as fossils, an acknowledged superiority in the correlation of strata ; they are, moreover, capable of contributing evidence as to conditions of deposition and climate. Their evidence is now applied practically in the investigation of oilfield geology, particularly in America, but it has hitherto not been extensively utilized elsewhere.

PREVIOUS WORK.

Brady (in T. R. Jones, " Microzoa of the Valley-Deposits of the Nar, Norfolk," GEOL. MAG., 1865, p. 307) records three species from brickearth, *Rotalia beccarii, Nonionina striato-punctata,* and *N. depressula.*

The Monograph of the Foraminifera of the Crag, by Rupert Jones and others (1866–97, *Pal. Soc.*, i–xv, 1–402, pls. i–vii, 30 woodcuts) deals almost entirely with the earlier Pliocene faunas, the only contact with the present investigation being the lists of Chillesford Crag foraminifera on pp. v and 78. On p. v, from Chillesford are recorded :—

Polymorphina lactea.
Bulimina elegans.
Truncatulina lobatula.
Rotalia beccarii.
Polystomella crispa.
P. striatopunctata.

A note states : " The few kinds of foraminifera yielded by the Chillesford Crag . . . indicate a rather cold and shallow sea, perhaps somewhat brackish too, as their probable habitat."

On p. 78 from the Chillesford Beds of Aldeby are recorded :—

Nodosaria raphanus.
Textilaria globulosa.
Polymorphina tuberculata.
Planorbulina mediterranensis.

Brady (in Clement Reid, "The Pliocene Deposits of Britain," 1890, *Mem. Geol. Surv. U.K.*, table xiii, 284–8) lists from the Chillesford Crag the same six species noted above, giving the Crag Monograph as his authority. From the Weybourn Crag, however, he lists the following nine species, three doubtfully, which appear to be omitted from the Crag Monograph :—

Lagena squamosa (Montagu) ?
L. sulcata (Walker and Jacob) ?
Miliolina pulchella (d'Orbigny) ?
Polymorphina compressa d'Orbigny.
P. lactea (Walker and Jacob).
Polystomella arctica Parker and Jones.
P. crispa (Linné).
Rotalia beccarii (Linné).
Truncatulina lobatula (Walker and Jacob).

Indigenous foraminifera from boulder clays and sand, identified by Joseph Wright, are recorded by Professor J. W. Gregory (*Evolution of the Essex Rivers and of the Lower Thames*, 1922, 8vo, Colchester). The following species are listed (pp. 13, 14) from Ballingdon brickfield, south of Sudbury, in North Essex :—

Miliolina seminulum (L.).
Bulimina fusiformis Will.
Bolivina plicata d'Orb.
Lagena laevigata (Reuss).
L. hexagona (Will.).
Pulvinulina karsteni (Reuss).
Pulvinulina auricula (F. and M.).
Rotalia beccarii (L.).
Nonionina depressula (W. and J.).
N. stelligera d'Orb.
Polystomella arctica (P. and J.).
P. striatopunctata (F. and M.).

Wright wrote : " Derived chalk forams were in great profusion in all the samples, I should say some hundreds to every Pleistocene specimen," and " . . . *N. depressula* and *P. striatopunctata* were the only species that were represented by more than one example . . . "

Dr. R. L. Sherlock lists foraminifera from two specimens of glacial sand from Hertfordshire (in Sherlock and Pocock, " The Geology of the Country around Hertford." Explanation of Sheet 239, 1924, *Mem. Geol. Surv. England and Wales,* pp. 55–6). He states, however, that " all are Cretaceous forms and most of them might have been derived from either Chalk or Gault ". An " incomplete examination " yielded twenty-four and nineteen species respectively from the two specimens, all but five being specifically identified.

Williamson had foraminifera from post-Pliocene clays and sands from March, Cambridgeshire, and Boston, Lincolnshire. These localities are found in two of his papers noted under the descriptions of such species as he recorded from them " On the Recent Species of the Genus *Lagena*," 1848, *Ann. Mag. Nat. Hist.* (2), i, 1–2, footnote, etc. ; and " The Recent Foraminifera of Great Britain," 1858, *Ray Soc.*, p. viii, etc.).

Parker and Jones (" On some Foraminifera from the North-Atlantic and Arctic Oceans, including Davis Straits and Baffin's Bay," 1865, *Phil. Trans.*, clv, 325-441, pls. xii-xix) list in Table vii the foraminifera from four specimens of sub-recent clays, two from Peterborough Fen, one from Boston, Lincolnshire, and one from Wisbech, Cambridgeshire.

These last two papers, however, appear to deal with faunas of later date than the glacial deposits of East Anglia, and need not be further considered here.

EXTRACTION OF FORAMINIFERA.

Sands were washed directly, but clays were broken into fragments the size of a walnut or smaller and thoroughly dried ; dropped into water and left for a couple of hours or more they were usually found to have become a mud. After washing by decantation until the residue was quite clean, any pebbles were removed, and if the quantity was large it was panned to concentrate the lighter material, which includes the foraminifera. This concentrate was thoroughly dried, and most of the foraminifera separated from the sand by

Ozawa's method of flotation in carbon tetrachloride. Heavy forms and some specimens with mineral infilling, however, do not float, and must be sought in the other fraction. The Chalk species, and even some of the Jurassic species, were usually found in the floated fraction.

Some two or three pounds of clay or sand were collected in each case, with the exception of No. 8, below, and treated as above.

THE FORAMINIFERAL FAUNAS.

Out of the twelve divers samples collected foraminifera were found in eleven as detailed below. No foraminifera were found in the specimen which was examined from the Norwich Brickearth from Ruymp's Pit, Sprowston, near Norwich.

The faunas of these deposits are peculiar in that they consist largely of foraminifera derived from much older strata. Eventually, it may be possible to assign some of these derived faunas to more restricted horizons than is here done, but much more work will be necessary on the foraminifera of known Jurassic and Cretaceous zones before this becomes practicable. It is evident that, in dealing with such a mixed fauna, the original age of whose components varies from Jurassic to Quarternary, there is unusually great opportunity for error, both in the determination of species and in the assignation to their original horizon, and such possibilities must be allowed for in the results.

The age of the foraminifera of these deposits can be determined partly by a knowledge of the time ranges of the species, and partly by the state of preservation of the specimens. The indigenous forms often have the tests empty, and they might be taken for a recent gathering, while certain living species among them, e.g. *Elphidium arcticum*, are not known from strata earlier than the Pleistocene. One form, *Pseudopolymorphina variata* var. *fischeri* appears to be known only from the late Tertiary of Europe, in particular from the Coralline Crag.[1] In this and in other species possibly assignable to the Lower Pliocene there is often a peculiar iron-staining of the tests which are sometimes empty. The opaque whiteness of the chalk-filled Chalk species is entirely characteristic and indicates their provenance without more ado; in addition, many of the species are distinctive. The Jurassic species (which may conceivably include some Lower Cretaceous or Gault specimens) sometimes approach the indigenous forms in the excellence of their preservation and general appearance, but they are sometimes iron-stained and the species are distinctive. A final residue remains of forms it has not yet been found possible to assign with confidence to any horizon, though most are probably indigenous or lower Pliocene.

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[1] In the Crag Monograph it appears under the name *Polymorphina compressa*, p. 258, pl. i, figs. 54, 65, 77–80; distorted specimens, pl. v, figs. 26, 28.

DATA OF THE ROCK SAMPLES EXAMINED.

Pliocene.

1. Weybourn Crag; from lowest 2 feet, overlying Chalk; coast section, Weybourn. Foraminifera very few, poorly preserved, but of moderate size; nearly all indigenous; mainly *Elphidium arcticum.*

2. Chillesford Beds; clayey sand of uppermost 3 feet, underlying recent wash; pit close behind Chillesford Church. Foraminifera abundant, well preserved, mainly large; nearly all indigenous; abundant *Elphidium arcticum, Rotalia beccarii,* and the mock-foraminifer.

From this sample were also washed some tiny fish vertebrae and the broken bone of a bird, which has been kindly identified by Miss D. M. A. Bate as "the proximal end of a right radius of *Uria* sp. It undoubtedly belongs to one of the Alcidae and resembles very closely the corresponding bone of the Recent *Uria troille,* the Guillemot." This bone is preserved in the British Museum (Natural History), Regd. No. A. 1940.

Pleistocene.

3. "Lower Till," overlying Forest Bed; coast section between Bacton and Paston. Foraminifera fairly numerous, very small; mainly Chalk; *Eouvigerina cretacea* and *Pseudotextularia globulosa* frequent.

4. Cromer Till; landslip on the beach, half a mile east of Cromer. Foraminifera fairly numerous, very small; mainly Chalk and indigenous; of the Chalk *Pseudotextularia globulosa* and *Globigerina aspera* are frequent.

5. Boulder clay; coast section, Happisburgh. Foraminifera fairly numerous, very small; mainly Chalk and indigenous; of the Chalk *Pseudotextularia globulosa, Eouvigerina cretacea* and *Globigerina aspera* are frequent.

6. Chalky-Jurassic Boulder Clay; Mason's Pit, Claydon. Foraminifera abundant, small and medium sized; mainly Chalk and Jurassic; of the Chalk *Eouvigerina cretacea, Pseudotextularia globulosa* and *Globotruncana linneiana* are frequent; of the Jurassic *Cristellaria quenstedti* is prominent.

7. Norwich Brickearth, below the sands; coast section, near Cliff House, Ormsby. Foraminifera fairly numerous, small; mainly Chalk and indigenous with a sprinkling of Jurassic; of the Chalk *Pseudotextularia globulosa* and *Globigerina aspera* are frequent.

8. Glacial sands, underlying Chalky-Jurassic boulder clay; coast section, Ormsby. (Small sample taken close to the steps.) Foraminifera fairly numerous, of fair size; almost wholly indigenous, definite Chalk and Jurassic forms lacking; *Cibicides lobatula* abundant, *Elphidium arcticum* and *Bulimina marginata* frequent.

9. *Leda myalis* Bed (sands); coast section, West Runton. Foraminifera abundant, many of good size, the smallest sized material is

THE INDIGENOUS FAUNA.

		Pliocene.		Pleistocene.									
		Weybourn Crag.	Chillesford Beds.	Boulder Clay, Bacton-Paston.	Cromer Till.	Boulder Clay, Happisburgh.	Ch.-J. Boulder Clay, Claydon.	Norwich Brick-earth, Ormsby.	Glacial Sands, Ormsby.	*Leda myalis* Bed, West Runton.	Glacial Sands, Corton.	Sand and Clay, Hunstanton.
		1	2	3	4	5	6	7	8	9	10	11
1.	Mock-foraminifer	—	C	—	—	—	—	—	—	—	—	—
2.	*Haplophragmoides canariensis* (d'Orbigny)	—	—	—	—	1	—	—	—	—	—	—
3.	*Glomospira gordialis* (Jones and Parker)	—	—	—	—	—	—	—	—	—	—	1
4.	*Trochammina globigeriniformis* (Parker and Jones)	—	—	—	—	1	—	—	—	—	—	—
5.	*Verneuilina advena* Cushman	—	—	—	4	—	—	4	—	—	—	3
6.	*Bulimina affinis* d'Orbigny	—	—	—	6	—	1	3	—	5	9	—
7.	*B. brevis* d'Orbigny	—	—	3	—	6	4	—	—	2	8	6
8.	*B. marginata* d'Orbigny	—	—	—	—	—	—	—	10	—	—	5
9.	*B. pupoides* d'Orbigny	—	4	1	—	3	—	—	—	—	—	1
10.	*Bolivina minutissima* Spandel	—	—	—	—	1	—	—	—	—	—	—
11.	*Cassidulina crassa* d'Orbigny	—	—	—	2	2	—	3	—	—	—	10
12.	*C. laevigata* d'Orbigny	—	—	—	—	—	—	—	—	—	2	—
13.	*Lagena acuticosta* Reuss	—	—	—	—	—	—	—	—	—	2	1
14.	*L. laevigata* (Reuss)	—	—	—	—	—	—	—	—	1	—	—
15.	*L. semistriata* Williamson	—	—	—	—	—	—	—	—	—	—	1
16.	*L. squamosa* (Montagu)	—	—	—	2	—	—	—	—	—	—	—
17.	*L. striata* (d'Orbigny)	—	—	—	—	—	—	—	—	—	4	—
18.	*L. sulcata* (Walker and Jacob)	—	—	3	—	—	—	—	—	—	—	2
19.	*Nodosaria calomorpha* Reuss	—	—	1	1	—	—	—	—	—	—	—
20.	*N. consobrina* var. *emaciata* Reuss	—	—	1	—	—	—	—	—	—	—	—
21.	*Cristellaria crepidula* (Fichtel and Moll)	—	—	—	—	—	1	—	—	—	—	—
22.	*C. papillosa* (Fichtel and Moll)	—	—	—	—	—	—	—	—	—	1	—
23.	*Globulina gibba* var. *myristiformis* (Williamson)	—	—	—	—	—	—	—	—	—	11	—
24.	*G.* aff. *glacialis* Cushman and Ozawa	—	—	—	—	—	—	—	—	1	—	—
25.	*Anomalina rotula* (d'Orbigny)	—	—	1	—	—	—	—	—	—	—	—

26. *Planulina parisiensis* (d'Orbigny)	—	—	—	—	—	—	—	—	—	1	—
27. *Cibicides lobatula* (Walker and Jacob)	3	—	—	1	1	—	1	C	3	12	4
28. *Eponides repanda* (Fichtel and Moll)	—	—	3	—	—	—	—	—	3	5	—
29. *E.* aff. *schreibersii* (d'Orbigny)	—	—	—	—	—	1	—	—	—	—	—
30. *Rotalia beccarii* (Linné)	—	C	—	1	3	—	—	—	6	X	3
31. *Epistomina elegans* (d'Orbigny)	—	—	—	—	1	—	—	—	—	—	—
32. *Nonion depressulum* (Walker and Jacob)	1	—	—	—	—	—	2	—	2	—	—
33. *N. orbiculare* (Brady)	—	—	—	2	4	5	—	—	5	2	11
34. *N. pauperatum* (Balkwill and Wright)	—	—	—	—	2	—	—	—	—	—	—
35. *N.* sp. juv. ?	2	—	5	—	4	4	9	—	—	—	—
36. *Elphidium arcticum* (Parker and Jones)	12	C	—	4	2	—	7	X	6	C	3
37. *E.* aff. *crispum* (Fichtel and Moll)	1	2	—	—	—	—	—	—	3	14	—
38. *E. incertum* (Williamson)	1	—	2	3	6	9	—	—	15	4	10
39. *E. incertum* var. *clavatum* Cushman	—	15	—	—	1	—	6	—	5	—	2
40. *Faujasina carinata* d'Orbigny	—	—	—	—	—	—	—	—	—	3	—
SPECIES DERIVED FROM THE LOWER PLIOCENE.											
41. *Pseudopolymorphina variata* var. *fischeri* (Terquem)	—	—	—	—	—	—	—	—	—	1	—
FAUNA DERIVED FROM THE CHALK.											
42. *Haplophragmoides nonioninoides* (Reuss) ?	—	—	1	—	—	—	—	—	—	—	—
43. *Textularia trochus* var. *subconica* Franke	—	—	—	—	1	2	—	—	—	—	—
44. *Verneuilina bronni* Reuss	—	—	—	—	—	—	—	—	5	5	—
45. *V. tricarinata* d'Orbigny	—	—	—	—	—	—	—	—	—	6	—
46. *Gaudryina oxycona* Reuss	—	—	—	—	—	3	—	—	5	1	—
47. *G. rugosa* d'Orbigny	—	—	—	—	—	1	—	—	—	3	—
48. *G. trochoides* Marsson	—	—	—	—	—	—	—	—	—	6	—
49. *Bulimina acuta* Reuss	—	—	—	—	—	—	—	—	1	—	1
50. *Heterostomella foveolata* (Marsson)	—	—	1	—	—	1	—	—	4	8	—
51. *Arenobulimina brevicona* (Perner) ?	—	—	—	—	—	2	—	—	—	—	—
52. *A. obesa* (Reuss)	—	—	2	2	—	3	1	—	7	4	2
53. *A. obliqua* (d'Orbigny)	—	1	2	—	—	2	—	—	2	12	2
54. *Bolivina decorata* Jones	—	—	14	3	1	15	1	—	10	3	8
55. *B. incrassata* Reuss	—	—	6	—	1	—	—	—	11	9	—
56. *B. quadrilatera* (Schwager)	—	—	6	—	2	2	1	—	1	—	2
57. *Pseudotextularia globulosa* (Ehrenberg)	—	—	X	X	X	X	X	—	4	—	X
58. *Eouvigerina aspera* (Marsson)	—	—	2	—	1	1	—	—	—	—	2

	Pliocene.		Pleistocene.								
	Weybourn Crag.	Chillesford Beds.	Boulder Clay, Bacton-Paston.	Cromer Till.	Boulder Clay, Happisburgh.	Ch.-J. Boulder Clay, Claydon.	Norwich Brick-earth, Ormsby.	Glacial Sands, Ormsby.	*Leda myalis* Bed, West Runton.	Glacial Sands, Corton.	Sand and Clay, Hunstanton.
	1	2	3	4	5	6	7	8	9	10	11
59. *E. cretacea* (Heron-Allen and Earland)	—	—	X	10	X	X	6	—	5	—	X
60. *Pleurostomella barroisi* Berthelin	—	—	—	—	—	1	—	—	—	—	—
61. *P. subnodosa* Reuss	—	—	1	—	—	4	—	—	—	—	1
62. *Lagena apiculata* Reuss	—	—	1	—	—	—	—	—	1	1	1
63. *L. aspera* Reuss	—	—	—	—	—	—	—	—	—	4	—
64. *L. globosa* (Montagu)	—	—	—	—	—	—	—	—	—	3	—
65. *Nodosaria affinis* Reuss ?	—	—	—	—	—	—	—	—	1	3	1
66. *N. amphioxys* Reuss	—	—	—	—	—	—	—	—	—	—	1
67. *N. aspera* Reuss	—	—	1	—	—	—	—	—	—	2	—
68. *N. communis* (d'Orbigny)	—	—	1	—	1	—	—	—	—	4	—
69. *N. oligostegia* Reuss	—	—	—	—	—	—	—	—	—	3	—
70. *Frondicularia capillaris* Reuss	—	—	—	—	—	—	—	—	—	1	—
71. *F. striatula* Reuss	—	—	—	—	—	—	—	—	—	1	—
72. *F. turgida* Reuss	—	—	—	—	? 1	—	—	—	—	2	—
73. *Triplasia globulifera* (Reuss)	—	—	—	—	—	—	—	—	1	2	—
74. *Marginulina glabra* d'Orbigny	—	—	—	—	—	—	—	—	—	1	—
75. *M. seminotata* Reuss	—	—	—	—	—	—	—	—	—	1	—
76. *Cristellaria grata* Reuss	—	—	—	—	—	—	—	—	—	1	—
77. *C. navicula* d'Orbigny	—	—	1	—	1	—	—	—	1	1	2
78. *C.* sp. cf. *pachynota* Reuss	—	—	—	—	—	—	—	—	—	1	—
79. *C. recta* d'Orbigny	—	—	—	—	—	—	—	—	1	2	—
80. *C. rotulata* (Lamarck)	—	1	1	1	1	6	—	—	—	8	—
81. *C. triangularis* d'Orbigny	—	—	—	—	—	—	—	—	3	5	1
82. *Flabellina interpunctata* von der Marck	—	—	—	—	—	—	—	—	1	4	—
83. *F. reticulata* Reuss	—	—	—	—	—	—	—	—	—	2	—
84. *F. rugosa* d'Orbigny	—	—	—	—	—	2	—	—	1	1	—
85. *Guttulina adhaerens* Olszewski	—	—	—	—	—	—	—	—	—	2	—

86.	*Pyrulina acuminata* d'Orbigny	—	—	—	—	—	—	—	—	—	1	—
87.	*Ramulina aculeata* Wright	—	—	—	—	—	—	—	—	1	1	—
88.	*Pullenia sphaeroides* d'Orbigny	—	—	5	1	—	2	1	—	5	8	2
89.	*Globigerina aspera* (Ehrenberg)	—	—	X	X	X	10	X	—	—	—	X
90.	*G. cretacea* d'Orbigny	—	—	7	5	4	5	4	—	3	5	7
91.	*Globotruncana linneiana* (d'Orbigny)	—	—	3	1	3	X	—	—	4	5	2
92.	*Valvulineria allomorphinoides* (Reuss)	—	—	—	—	1	—	—	—	—	—	—
93.	*Anomalina clementiana* (d'Orbigny)	—	—	—	2	1	6	—	—	7	4	3
94.	*A. lorneiana* (d'Orbigny)	—	—	—	—	1	—	—	—	—	1	—
95.	*Gyroidina depressa* (Alth)	—	—	—	—	—	1	—	—	—	1	—
96.	*G. exsculpta* (Reuss)	—	—	7	—	—	7	—	—	X	X	3
97.	*G. micheliniana* (d'Orbigny)	—	—	3	2	2	3	—	—	X	X	7
98.	*G. umbilicata* (d'Orbigny)	—	—	5	1	—	6	—	—	X	X	5
99.	*G. umbilicata* var. *nitida* (Reuss)	1	—	—	4	1	3	—	—	—	—	2

FAUNA DERIVED FROM THE JURASSIC.

100.	*Nodosaria matutina* (d'Orbigny)	—	—	—	—	—	2	—	—	—	—	—
101.	*N. multicostata* (Bornemann)	—	—	—	—	—	1	—	—	—	—	—
102.	*N. raphanus* (Linné)	—	—	—	—	1	2	—	—	—	6	—
103.	*N. tenuistriata* (Terquem)	—	—	1	1	—	—	1	—	—	—	—
104.	*Frondicularia tenera* (Bornemann)	—	—	—	—	—	1	2	—	—	—	4
105.	*F. terquemi* d'Orbigny	—	—	—	—	—	—	—	—	1	—	—
106.	*Marginulina acuticostata* Reuss	—	—	—	—	—	2	—	—	—	—	—
107.	*M. raphanus* (Linné)	—	—	—	—	—	5	2	—	—	—	—
108.	*Vaginulina harpa* (Roemer)	—	—	—	—	—	2	—	—	—	1	—
109.	*V. longuemari* (Terquem)	—	—	—	—	—	—	—	—	—	1	—
110.	*Cristellaria helios* Terquem	—	—	—	—	—	4	—	—	—	2	—
111.	*C. inaequistriata* (Terquem)	—	—	—	—	—	1	—	—	—	—	—
112.	*C. instabilis* Terquem	—	1	—	—	—	—	—	—	—	—	—
113.	*C. laminosa* Schwager	—	—	—	—	—	—	1	—	—	—	—
114.	*C. lituoides* Bornemann	—	—	—	—	—	—	—	—	—	1	—
115.	*C. normanniae* Terquem	—	—	—	—	—	2	—	—	—	—	—
116.	*C. quenstedti* Gümbel	—	—	—	—	—	6	—	—	—	—	—
117.	*Epistomina elegans* (d'Orbigny)	—	—	—	—	—	—	—	—	—	1	—

NOTE.—C = abundant ; X = frequent ; the numbers record how many specimens were picked out.

SPECIES OF DOUBTFUL AGE.

(Most are probably indigenous or of lower Pliocene age.)

		Pliocene.		Pleistocene.								
		Weybourn Crag. 1	Chillesford Beds. 2	Boulder Clay, Bacton-Paston. 3	Cromer Till. 4	Boulder Clay, Happisburgh. 5	Ch.-J. Boulder Clay, Claydon. 6	Norwich Brick-earth, Ormsby. 7	Glacial Sands, Ormsby. 8	*Leda myalis* Bed, West Runton. 9	Glacial Sands, Corton. 10	Sand and Clay, Hunstanton. 11
118.	*Textularia agglutinans* d'Orbigny	—	—	—	—	—	—	—	—	—	1	—
119.	*T. sagittula* Defrance	—	—	—	—	—	—	—	—	—	7	—
120.	*Verneuilina triquetra* (Münster)	—	—	—	—	—	—	—	—	6	—	—
121.	*Reussia spinulosa* (Reuss)	—	—	1	—	—	4	—	—	—	2	2
122.	*R. spinulosa* var. *glabrata* (Cushman)	—	—	1	—	—	6	1	—	2	2	1
123.	*Uvigerina aculeata* d'Orbigny	—	—	—	—	2	—	—	—	1	—	—
124.	*U. angulosa* Williamson	—	—	—	—	—	—	1	—	—	—	—
125.	*U. canariensis* d'Orbigny	—	—	—	—	—	—	1	—	—	—	—
126.	*Pleurostomella alternans* Schwager	—	—	—	—	—	—	1	—	1	—	—
127.	*Nodosaria obliquestriata* (Reuss)	—	—	—	—	—	—	—	—	—	1	—
128.	*Vaginulina legumen* (Linné)	—	—	—	—	—	—	—	—	2	1	—
129.	*Cristellaria cultrata* (Montfort)	—	—	—	—	—	—	—	—	—	—	2
130.	*Guttulina kishinouyi* Cushman and Ozawa ?	—	1	—	—	—	—	—	1	—	4	—
131.	*G. problema* d'Orbigny	—	—	—	—	—	—	—	—	—	2	—
132.	*Globulina gibba* var. *globosa* (Münster)	—	—	—	—	—	—	—	—	—	1	—
133.	*G. gibba* var. *longitudinalis* Cushman and Ozawa	—	—	—	—	—	—	—	—	—	1	—

SUMMARY TO SHOW THE NUMBER OF FORMS OF EACH ORIGINAL HORIZON RECORDED FROM EACH LOCALITY.

	Pliocene.		Pleistocene.								
	1	2	3	4	5	6	7	8	9	10	11
Indigenous	6	6	9	10	15	7	8	3	13	16	15
Lower Pliocene	—	—	—	—	—	—	—	—	—	1	—
Chalk	1	2	23	13	19	26	8	—	27	44	23
Jurassic	—	1	1	1	1	11	4	—	1	6	1
Age doubtful	—	1	2	—	1	2	4	1	5	10	3
Total fauna	7	10	35	24	36	46	24	4	[illegible]	[illegible]	[illegible]

lacking; largely Chalk, with some indigenous; of the Chalk *Gyroidina umbilicata*, *G. exsculpta* and *G. micheliniana* are frequent; of the indigenous, *Elphidium incertum* is frequent.

10. Glacial sands; coast section, Corton, near Lowestoft; collected from the wisps of white material in the sand cliff. This was by far the richest sample obtained, both in numbers and species. Foraminifera very abundant, many of good size; the smallest sized material is lacking; mainly indigenous and Chalk, with a considerable residue of species of doubtful age and some Jurassic forms; of the Chalk, *Gyroidina umbilicata*, *G. exsculpta*, and *G. micheliniana* are frequent; of indigenous species *Elphidium arcticum* is abundant and *Rotalia beccarii* common; of doubtful age (? Pliocene), Polymorphinidae of large size.

11. Sand and brown clay; south side of Gasworks Pit, Hunstanton. Foraminifera fairly abundant, generally small; almost wholly indigenous and Chalk; of indigenous species *Cassidulina crassa*, *Nonion orbiculare* and *Elphidium incertum* are frequent; of the Chalk, *Eouvigerina cretacea*, *Pseudotextularia globulosa* and *Globigerina aspera* are frequent.

For a summary of the stratigraphy of these deposits reference may be made to Professor P. G. H. Boswell's paper, "The Stratigraphy of the Glacial Deposits of East Anglia in relation to Early Man," *Proc. Geol. Ass.*, 1931, xlii, 87–111, where other references are to be found.

It may be added that the term "indigenous" as used in the present paper should perhaps not be taken too literally. The specimens so recorded may in some cases have been derived from very slightly older deposits by penecontemporaneous erosion.

It may be recorded that the problematical bodies known as "chalk spheres", of diameter varying from about 0·05 to 0·13 mm. and here derived from the Chalk, are abundant in the samples which contained Chalk foraminifera of the smallest size, in particular from Locs. 3, 4, 5, 6, 7, 11, above. The literature of these, or very similar bodies, found in strata of various geological ages down to the present day, is extensive, and they have received various names on the supposition that they are foraminifera. The evidence, however, seems to point to their being rather of inorganic, concretionary, origin. Ostracods were also obtained.

It will be observed that the commoner species of the Chalk faunas are sometimes *Pseudotextularia globulosa*, *Eouvigerina cretacea* and *Globigerina aspera*, which are all minute forms, and sometimes *Gyroidina umbilicata*, *G. exsculpta*, and *G. micheliniana*, which are considerably larger. Such differences may probably be accounted for merely by the concentration of different sized particles in the different deposits, rather than by derivation from more than one Chalk horizon.

PALAEONTOLOGICAL NOTES.

The revised nomenclature of the Foraminifera.

In view of the fact that a revised nomenclature, based on a strict application of the rule of priority, together with more restricted views on the width of a genus, has only recently come into common use, it may facilitate reference to the older literature to give the following correlation of generic names used in the present paper.

Revised Nomenclature.	*Former usage.*
Arenobulimina, Cushman, 1927.	*Bulimina* (pars).
Cibicides Montfort, 1808.	*Truncatulina* (pars).
Discorbis Lamarck, 1804.	*Discorbina.*
Elphidium Montfort, 1808.	*Polystomella.*
Eouvigerina Cushman, 1926.	*Sagrina* (pars).
Eponides Montfort, 1808.	*Pulvinulina* (pars).
Globotruncana Cushman, 1927.	*Globigerina* (pars).
Globulina d'Orbigny, 1826.	*Polymorphina* (pars).
Guttulina d'Orbigny, 1826.	*Polymorphina* (pars).
Gyroidina d'Orbigny, 1826.	*Rotalia* (pars). *Pulvinulina* (pars).
Haplophragmoides Cushman, 1910.	*Haplophragmium* (pars).
Nonion Montfort, 1808.	*Nonionina.*
Planulina d'Orbigny, 1826.	*Discorbina* (pars).
Pseudotextularia Rzehak, 1895.	*Gümbelina* *Textularia* (pars).
Pyrulina d'Orbigny, 1826.	*Polymorphina* (pars).
Reussia Schwager, 1877.	*Verneuilina* (pars)
Triplasia Reuss, 1853.	*Rhabdogonium.*
Valvulineria Cushman, 1926.	*Valvulina* (pars). *Discorbina* (pars).

Bolivina quadrilatera (Schwager), Pl. XXXV, Figs. 21*a*, *b*.

This is used (provisionally at least) as the valid name to include the Cretaceous as well as later specimens. I consider the synonymy to include the following :—

1859. *Textularia obsoleta* Eley, *Geology in the Garden*, 202, pl. viii, fig. 11*c* (non Reuss).

1866. *Textularia quadrilatera* Schwager, *Novara-Exped.*, *Geol.*, teil ii, 253, pl. vii, fig. 103.

1927. *Bolivinita eleyi* Cushman, *Contrib. Cushman Lab. Foram. Research*, ii, 91, pl. xii, figs. 11*a*, *b* ; (nom. nov. for *Textularia obsoleta*, Eley, not Reuss.).

1927. *Bolivinita planata* Cushman, op. cit., iii, 115, pl. xxiii, figs. 9*a*, *b*.

1927. *Plectofrondicularia quadrilatera* Liebus, *Jahrb. Geol. Bundesanst.*, Wien, lxxvii, 367, pl. xiii, figs. 6, 7*a*, *b*.

1928. *Bolivinita angelina* Church, *Journ. Pal.*, i, 265, text-figs. 1*a*, *b*.

Chapman states that " The Cretaceous specimens have a narrower habit of growth than the Pliocene or Recent ; otherwise there is no difference between them " (1917, " Monograph of the Foraminifera and Ostracoda of the Gingin Chalk," *Bull.* 72, *Geol. Surv. Western Australia*, 22). Cushman, in his description of *B. eleyi*, refers with approval to the first part of Chapman's sentence quoted above; but a study of available material does not confirm it, as the following figures show.

Specimen or Figure.	*Max. breadth, expressed as percentage of length.*
CRETACEOUS :—	
Eley's type-figure of *T. obsoleta* (Chalk of England)	40·7
Cushman's type-figure of *B. eleyi* (Arkansas, U.S.A.)	28·2
Chapman's figure of *B. obsoleta* (Eley), (Chalk of Western Australia)	35·7
Two specimens from Chalk of Gravesend, Kent .	36·2, 48·0
Sixteen specimens derived from the Chalk, (Pleistocene of East Anglia)	28·9 to 66·6; mean 43·3
Cushman's type-figure of *B. planata* (Texas, U.S.A.)	59·5
PLIOCENE :—	
Schwager's type-figure of *T. quadrilatera* (Nicobar Is., Bay of Bengal)	32·2
Topotype material sent by Schwager, now in the Brady Coll., Cambridge; three specimens .	29·9, 33·9, 35·2
Church's type-figure of *B. angelina* (California, U.S.A.)	35·2
RECENT :—	
Off New Zealand (Brady Coll., Cambridge); nine specimens	29·1 to 44·1; mean 34·8.

In view of this material, which appears to show a continuous series, the breadth varying from 28·2 per cent to 66·6 per cent of the length, it does not seem justifyable to separate the narrower from the broader forms even varietally.

It seems possible that either or both of Costa's species, *Textularia laminaris* (*Atti Ac. Pontaniana*, 1856, vii, fasc. 2, 290, pl. xxiii, figs. 15A, B, C, 16) and *T. tetraedra* (loc. cit., 288, pl. xxiii, figs. 10A, C), which were compared by Schwager, may represent *B. quadrilatera*, in which case one of these names would be the valid one. But without seeing Costa's specimens it is not possible to be at all certain of the matter.

Eouvigerina cretacea (Heron-Allen and Earland), Pl. XXXV, Fig. 23.

Amongst the East Anglian specimens, derived from the Chalk, few have a completely smooth surface as shown by the figured specimen. The majority are slightly to considerably rough or hispid, though they retain the same general character of the species. The completely hispid forms, recorded here as *E. aspera* (Marsson), are rare in the material, and the shape of the chambers is distinct, having a more rounded appearance.

Gaudryina trochoides Marsson.

This is used as the valid name for *G. crassa* Marsson, 1878, which name is preoccupied by Karrer, 1870. Marsson's *G. crassa* var. *trochoides* seems to be merely the young form, and the "varietal" name may therefore be taken to indicate the species.

"*Polystomella striatopunctata.*"

Attention may be directed to the frequent occurrence of this name, particularly in lists of foraminifera from British Boulder Clays and Recent gatherings. This unfortunate usage goes back to 1866 when Rupert Jones, Parker, and Brady figured a form under this name in the Crag Monograph (pl. ii, figs. 38, 39; described 1897, 350–352). This erroneous interpretation has been followed until very recently by most later authors. The forms indicated are quite distinct from the true *Elphidium striatopunctatum* (Fichtel and Moll), which is a recent species described from the "Sinus Arabicus", as pointed out by Cushman (1929, *Contrib. Cushman Lab. Foram. Research*, v, 19, pl. iv, figs. 5, 6), and of which I have abundant material from the Red Sea and Gulf of Aden. The "synonymy" given under the name in the Crag Monograph indicates the variety of forms included. Of the forms recorded in the present paper, *Nonion orbiculare*, *Elphidium incertum*, and *E. incertum* var. *clavatum* have in the past been included in records of "*P. striatopunctata*".

Bulimina pupoides d'Orbigny, Pl. XXXIV, Fig 4.

The specimen depicted was unfortunately figured in error; it is not typical of the species.

Vaginulina longuemari (Terquem).

I have recently examined two of Terquem's slides, one labelled "*Marginulina longuemari* Terq., pl. viii, figs. 18 à 19", in the Zool. Dept. (Vers et Crustacés), Museum National d'Histoire Naturelle, Paris, and the second, with three good specimens, labelled "*Marginulina longuemari* Terq., pl. viii, figs. 16–19", in the Lab. de Paléontologie, Mus. Nat. Hist. Nat., Paris; the plate and figure references are to Terquem's Third Memoir on the Lias Foraminifera (*Mem. Ac. Imp. Metz.*, **2**, xliv, 1863, 361–438, pls. vii–x). The specimens are all of the same form, but they do not agree with the type-figures and I have little doubt that they do not include the types; in my opinion they should be referred to *V. harpula* d'Orbigny.

Mock-Foraminifer, Pl. XXXIV, Fig. 1.

These structures, which simulate an arenaceous foraminifer of the family Astrorhizidae, appear to be incrustations of the rootlets of plants or algae. They occur as an irregular central chamber which gives off open, irregular tubes, usually found broken off. The wall is mainly calcareous but may include sand grains or other local material. The forms are often common in brickearths, etc., whence I have them from Orsett in Essex, Pegwell Bay in Kent, and Petit Près near Grignon, in the Paris Basin; and from brown glacial clay of Wingate Hill, near Tadcaster, Yorkshire. I am indebted to Dr. T. M. Harris for their identification; their designation is my own.

CONTEMPORARY CLIMATE AS INDICATED BY THE FORAMINIFERA.

Of the indigenous foraminifera recorded a few species live at the present day in restricted latitudes, and so may be presumed to have a value in the indication of the climatic conditions under which the late Pliocene and Pleistocene deposits in which they are found were laid down.

Two species in particular are typically northern forms; rare specimens of *Nonion orbiculare* have been recorded from the British area as far south as 52° N. Lat., while *Elphidium arcticum*, which is, in Brady's words, "exclusively boreal and almost exclusively Arctic", has similarly been recorded down to 53° 20′ N.

On the other hand a few species indicate conditions not appreciably colder, and in one doubtful case warmer, than obtain at present. *Rotalia beccarii* is now often excessively abundant in the British area, but its furthest northern record in the western Atlantic seems to be that of Hofker from the Faröe Islands in 62° N. Lat. It is, however, frequently recorded as a fossil in boulder clays in Britain by Joseph Wright.

Bulmina marginata has been recorded by Goes from Spitsbergen, but is not properly an Arctic species, and *Globulina gibba* var. *myristiformis* is, according to Cushman, common round the southern part of the British Isles but rarer in the northern part. It does not appear to be recorded from the Scandinavian area.

An important species, but of which the original age of the recorded specimens is in doubt, is *Reussia spinulosa.* This is a tropical to warm temperature species of which only a few rare specimens are found to-day in the British area, which seems to be its northern limit. *Eponides repanda* also is a typically warm-water species, though there are a few records of it from cooler waters. According to Brady, it is common in all parts of the world, except Arctic seas.

Solely from a consideration of the foraminiferal faunas and mainly from the indicators noted above, the following suggestions may perhaps, be made :—

Weybourn Crag.—The fairly common occurrence of *Elphidium arcticum* without definite warmer forms points to cold conditions, perhaps sub-arctic.

Chillesford Beds.—The abundance of *E. arcticum* points to cold conditions. But *Rotalia beccarii* is also abundant and appears to limit the degree of cold.

In the case of the Pleistocene deposits the foraminiferal evidence is somewhat conflicting. Of the two definitely cold indicators, *Nonion orbiculare* is never a common species, but occurs at localities 4, 5, 6, 9, 10, 11. *Elphidium arcticum* occurs at all but localities

3 and 6, which are both boulder clays, and is common at localities 8 and 10.

Assuming that the rare *Reussia spinulosa* is indigenous, the samples from localities 3, 6, 10, and 11 might point to a warmer climate than the rest, though 3 and 6 are boulder clays. *Bulimina marginata* from localities 8 and 11, *Globulina gibba* var. *myristiformis* from locality 10, and *Eponides repanda* from localities 3, 9, and 10, might again point to a more temperate climate.

The conclusion is that the foraminiferal faunas now found in these deposits indicate much erosion and mixing of faunas, perhaps partly as a result of penecontemporaneous erosion, or of warm or cold currents in the sea. The presence of " cold " species, when in considerable numbers, points to colder conditions than now obtain, but it will be observed that some of the samples, notably from localities 9, 10, and 11, contain both cold and temperate indicators. Taking the records at their face value, the coldest deposits, in that temperate indicators are not recorded from them, are localities 4, 5, and 7, i.e., the Cromer Till, the Happisburgh boulder clay, and the Norwich Brickearth. The warmest deposit, in that cold indicators are not recorded, is locality 3, the boulder clay between Bacton and Paston. Whether these first indications can be substantiated must await further work.

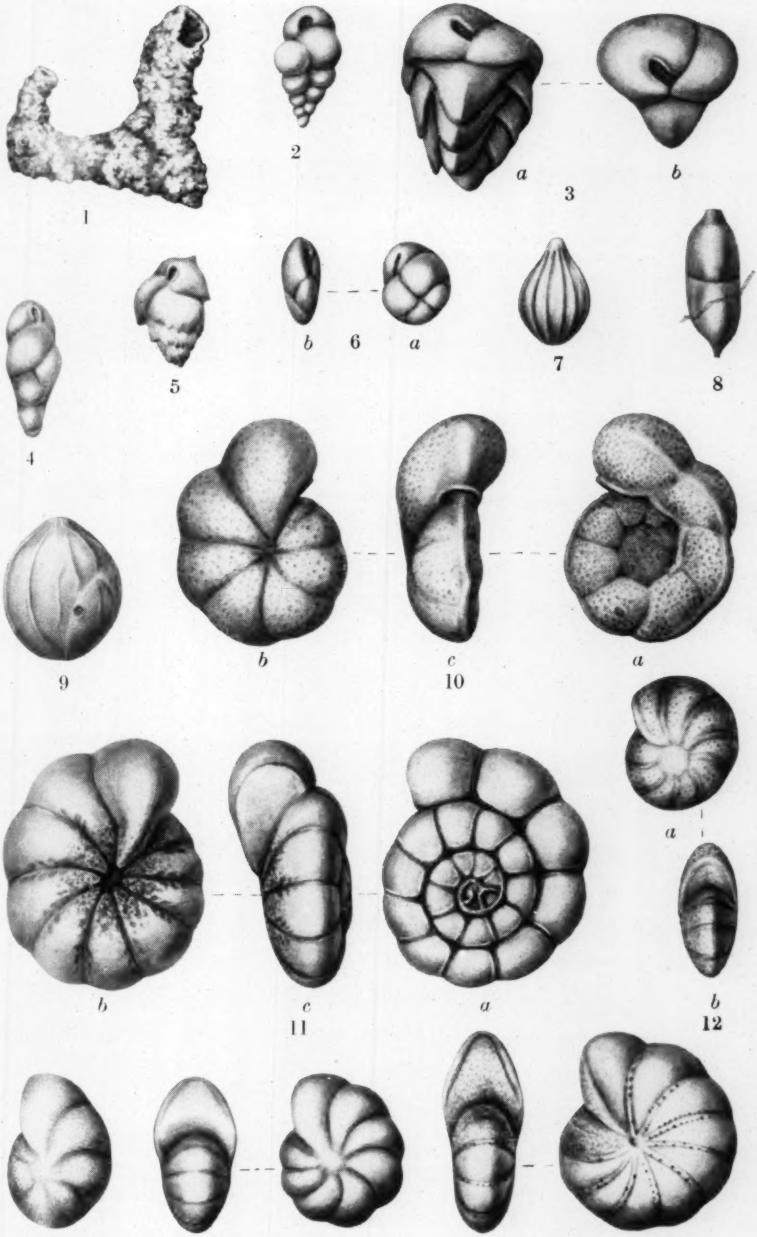
In the preparation of this paper I am much indebted to Professor P. G. H. Boswell, F.R.S., and Mr. A. G. Brighton for helpful criticism. I have also to thank Mr. C. Forster Cooper for access to the Brady Collection of foraminifera preserved in the University Zoological Museum at Cambridge, Professor Marcellin Boule, and Professor C. Gravier, for access to the collections of foraminifera preserved in the departments of Palaeontology and Zoology (Vers et Crustacés) respectively of the Museum National d'Histoire Naturelle, in Paris.

EXPLANATION OF PLATES XXXIV AND XXXV.

PLATE XXXIV.

Pleistocene and Pliocene Specimens.

FIG.
1.—Mock-foraminifer, × 9. Loc. 2.
2.—*Verneuilina advena* Cushman, × 91. Loc. 11.
3*a*, *b*.—*Reussia spinulosa* var. *glabrata* (Cushman), × 91. Loc. 11.
4.—*Bulimina pupoides* d'Orbigny (?), × 45. Loc. 2.
5.—*Bulimina marginata* d'Orbigny, × 45. Loc. 11.
6*a*, *b*.—*Cassidulina crassa* d'Orbigny, × 45. Loc. 11.
7.—*Lagena sulcata* (Walker and Jacob), × 45. Loc. 3.
8.—*Nodosaria calomorpha* Reuss, × 91. Loc. 3.
9.—*Globulina gibba* var. *myristiformis* (Williamson), × 45. Loc. 10.
10*a*–*c*.—*Cibicides lobatula* (Walker and Jacob), × 45. Loc. 10.
11*a*–*c*.—*Rotalia beccarii* (Linné), × 45. Loc. 10.
12*a*, *b*, 13.—*Nonion* sp. juv. ?, × 91. Loc. 7.
14*a*, *b*.—*Nonion orbiculare* (Brady), × 45. Loc. 11.
15*a*, *b*.—*Elphidium arcticum* (Parker and Jones), × 45. Loc. 10.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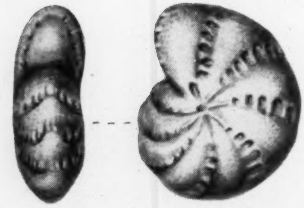
Foraminifera, etc., of East Anglia.

[*To face p.* 496.



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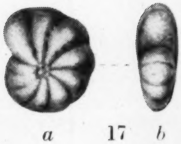

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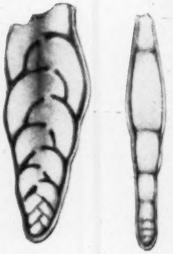

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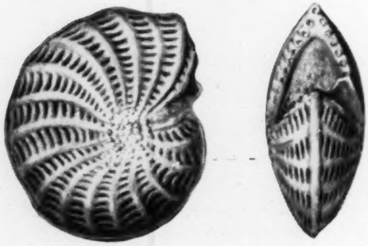

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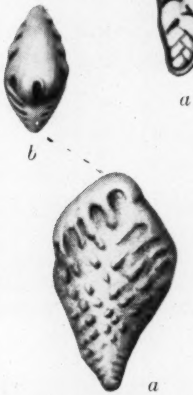

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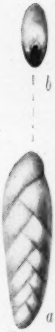

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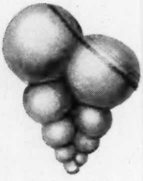
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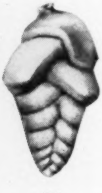
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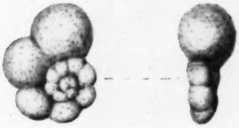

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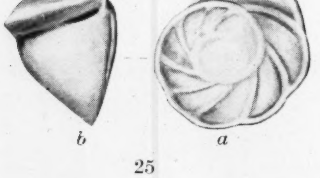

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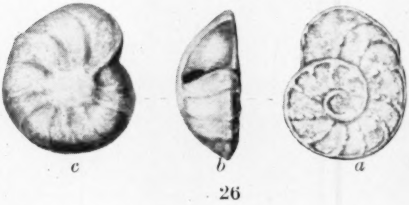

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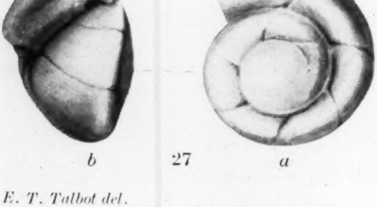

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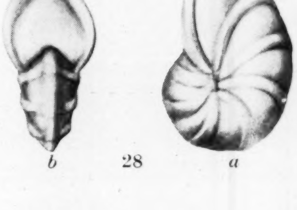

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PLATE XXXV.

Pleistocene and Pliocene Specimens.

FIG.
16*a*, *b*.—*Elphidium incertum* (Williamson), × 45. Loc. 5.
17*a*, *b*.—*Elphidium incertum* var. *clavatum* Cushman, × 45. Loc. 2.
18*a*, *b*.—*Elphidium* aff. *crispum* (Fichtel and Moll.), × 45. Loc. 10.

Specimens derived from the Chalk.

19*a*, *b*.—*Bolivina incrassata* Reuss, × 45. Loc. 9.
20*a*, *b*.—*Bolivina decorata* Jones. × 45. Loc. 10.
21*a*, *b*.—*Bolivina quadrilatera* (Schwager), (glycerine mount), × 91. Loc. 3.
22.—*Pseudotextularia globulosa* (Ehrenberg), × 91. Loc. 11.
23.—*Eouvigerina cretacea* (Heron-Allen and Earland), × 91. Loc. 11.
24*a*, *b*.—*Globigerina aspera* (Ehrenberg), × 91. Loc. 11.
25*a*, *b*.—*Gyroidina micheliniana* (d'Orbigny), × 45. Loc. 10.
26*a*–*c*.—*Gyroidina exsculpta* (Reuss), × 45. Loc. 10.
27*a*, *b*.—*Gyroidina umbilicata* (d'Orbigny), × 45. Loc. 10.

Specimen derived from the Jurassic.

28*a*, *b*.—*Cristellaria quenstedti* Gümbel, × 45. Loc. 6.

Petrology and the Western Rift of Central Africa.

By A. W. GROVES, PH.D., M.SC., D.I.C., F.G.S.

(PLATES XXXVI–VIII.)

IN the course of several journeys between Masindi and Butiaba, and one from Butiaba to Hoima (via Waki Camp), specimens of the various gneisses were collected from roadside exposures. Thin sections of these were subsequently studied by the writer in England with the result that they were found to yield evidence of tectonic significance. In addition, the writer has, during the last three years, examined petrographically a large number of other rocks from those parts of Uganda bordering the Lake Albert Depression. In particular he has made a special study of the Charnockite Series, which are widely spread over the northern half of the Protectorate, with the result that it has been possible to observe the effects of the rift valley movements on these rocks in the regions adjacent to Lake Albert. It is hoped to publish a petrological and geochemical study of the Charnockite Series of Uganda in the near future. In the following pages it is proposed in Part I to present petrological evidence from the basement rocks of various districts in the hinterland of the Lake Albert scarps and then in Part II to point out the tectonic significance of this evidence in the light of the various theories of rift valley formation. In Part III the relation between the petrological characters of the volcanic rocks and the rift valley tectonics will be briefly reviewed. In the case of the basement rocks the remarks will be confined to the Lake Albert Depression, but in the case of the volcanic rocks the discussion will extend also to Lakes George and Edward and the Birunga volcanic field.

PART I.

Masindi to Butiaba.—On leaving Masindi there are a few small exposures of weathered shale, probably the Bunyoro Tillite, but with this exception there are no roadside exposures until Mile 26 from Masindi. At this point the road wends its way round the base of a large hill, one of a ridge running east-north-east–west-south-west parallel to the escarpment but some 8 or 9 miles east of it. From here down to the crest of the escarpment the road descends gradually in a series of steps giving rise to the impression that there is a series of step faults or more probably thrust blocks.

Specimens G. 69 and G. 70 come from the foot of the aforementioned hill. In the hand specimen they are very dark in colour and appear to be basic rocks, possibly altered dolerites. In thin section, however, they are found to be nothing of the kind.

G. 69.—The rock displays " mortar-structure " under the microscope. The large granules of felspar are of a fairly uniform size of 0·75–1·0 mm. while at their margins there is mylonized debris. The felspar granules all display microperthitic intergrowth on a very microscopic scale. This is precisely similar to what has been noted in other parts of the Protectorate, particularly the West Nile Dist., among rocks showing pronounced plutonic metamorphism and associated with the charnockite series. The " fibres " of the microperthitic intergrowth are frequently puckered and complicated by undulatory extinction. Some of it appears to be microcline-microperthite on an extremely fine scale. All of the quartz is of the recrystallized type associated with plutonic metamorphism, some of it occurring poecilitically as small rounded blebs in the midst of felspar crystals. There is also a later quartz of more secondary appearance.

Around many of the quartz patches, particularly those which appear to be later, there is a border of very small acicular crystals of an intensely deep bluish-green amphibole. A dark green band passing through the slide is due to the elongated patches of this amphibole and quartz along an old fracture. Odd needles of amphibole also occur in the felspar granules. A crystal of purple zircon present has an ovoid outline, its solid angles having been rounded off either mechanically or by re-solution. It is noteworthy that its vertical axis is parallel to the foliation direction and to the microperthitic structure in the neighbouring felspars. Other zircons are similarly rounded.

In another slide there is much more late secondary quartz and also epidote associated with the amphibole. While some patches are more or less equigranular, others show " mortar-structure ", and others again show intense mylonization to a fine " flour ". Some striking lines of thrusting with a zone of mylonization of a total width of only 2–3 mm. are to be observed.

This rock has assumed its granular texture under conditions amounting to plutonic metamorphism. The " mortar-structure ", microscopic thrusts, and mylonization, however, have been brought about by some severe earth movements subsequent to the cessation of conditions of plutonic metamorphism, that is to say after the rock had been brought by denudation nearer to the surface. The amphibole and its associated quartz and epidote are also clearly secondary and connected with these movements. The myriads of minute acicular crystals of deep bluish-green amphibole have given rise to the dark colour of the rocks, this being a secondary effect.

G. 70.—Under the microscope this is seen to be a very similar type of rock to G. 69. It has definite lines of fracture passing through it with a width of 3–4 mm. These fracture zones are occupied by debris of mylonized quartz and felspar while needles of bluish-green amphibole grow into the rock from either side. All the larger felspar granules are traversed by large cracks due to earth movements. The density of this rock, about 2·6, corresponds to an acid type.

G. 71.—This specimen comes from a little further on towards Butiaba at a point where there is a sharp right-hand bend in the road with exposures on both sides.

Under the microscope this is seen to be another rock of the plutonic-metamorphic type. The felspar shows the same exceedingly fine scale microperthitic intergrowth. The crystals of felspar are all very severely shattered, while much mylonized debris of quartz and felspar occupies the intervening spaces. The rock constitutes a crush breccia on a microscopic scale. The crystal fragments are aligned, i.e. the foliation which has been developed appears to be due to crushing. One main direction of shear is dominant and the main fractures in the larger felspar granules noticeably preponderate in the direction of foliation, but a few lines of fracture, possibly due to a tendency to thrusting, run across the slide at 45° to the direction of foliation. Minute needles of very deep bluish-green amphibole are formed parallel to the direction of foliation.

G. 72.—From a roadside exposure where a tributary of the River Waki comes nearest to the Masindi–Butiaba Road, about 9 miles from Butiaba and 2 miles from the crest of the scarp at Bukumi Camp. This is a dark coloured rock of which little can be learned from the hand specimen.

Under the microscope it can be recognized as a shattered and altered member of the charnockite series, other rocks of this series occurring only a few miles away on the Butiaba–Hoima Road. All the normal rocks of this series display equigranular texture but this particular one shows every indication that the rock has undergone severe mechanical strain. In spite of this, however, there is no tendency to foliation. The felspar crystals are shattered *in situ*, the various particles belonging to the same parent crystal still extinguishing more or less together. The effect appears to be that of a rock which has been subjected to intense pressure—perhaps in part caused by heating—and on the release of this the constituent crystals have disrupted themselves. None of the pyroxene remains, but confused aggregates of decomposition products occur in patches the shape of which suggest the former presence of pyroxene or amphibole. There are unmistakable signs of decomposed reaction fringes, such as occur in the neighbouring rocks of the charnockite series.

G. 73.—A typical mylonite occurring along the whole length (50 yards or so) of a small road cutting on a left-hand bend in the road (going towards Butiaba) at the top of the scarp, a few hundred yards above Bukumi Rest Camp and quite close to the memorial stone.

Slight weathering breaks the rock into slabs up to 6 inches in length parallel to the direction of foliation. The thickness of the slabs is about 2 to 3 inches but, on being gently struck with the hammer, they can be roughly cleaved into pieces only half an inch or less in thickness. The reason for this is clearly seen in the slides. The " cleavage " is along the main foliation direction, which is manifest both *en masse* in the road cutting and in the thin section. Transverse cracks in those folia consisting of quartz are abundant and being perpendicular to the planes of foliation and cleavage cause the cleaved pieces to be in the form of slabs. These cracks, which only occur in the quartz folia and lenses, are perpendicular to the longest sides and are fairly equally disposed along the length. They do not penetrate the intervening folia of finely milled quartz-felspar debris. It is a kind of freestone jointing on a small scale, probably due to cooling when the thrusting had subsided. The degree of mylonization is severe in the extreme, and, although most of it is in the form of an exceedingly fine " flour ", strangely enough some small rounded grains of felspar still remain. Close examination of these grains show that they are finely microperthitic and very similar to the felspar of the plutonic metamorphics and charnockite series of the rift scarp hinterland of this neighbourhood.

Bukumi Camp to Kigarobya.—Leaving the Masindi–Butiaba Road and commencing along the Waki Camp and Hoima Road, which for some miles travels in a direction parallel to, but several miles back from, the top of the scarp, rocks of the charnockite series are soon encountered in numerous roadside exposures. A detailed petrographical examination of these rocks commenced in Uganda is now being completed in England. It suffices here to say that they have undergone a good deal of crushing and dynamo-metamorphism at some time long subsequent to the main crystallization, as is evidenced by the shattering of crystals, crush zones on a microscopic scale, fraying of crystal outlines, and bending of twin lamellae. One specimen from near Waki Camp is a thorough mylonite. In addition to mechanical disintegration, all stages can be traced of the conversion of hypersthene into garnet through reaction with the surrounding felspar, much secondary dark mica is developed in the microscopic crush zones, while there is the usual plentiful production—coupled, probably, with introduction—of secondary silica. In some of the more basic types collected from the scarp slope in the neighbourhood of the R. Waki by Mr. A. D. Combe, garnet is very abundant indeed, what are probably former dolerite dykes having been converted by dynamo-metamorphism into garnet-amphibolites. As might be expected garnet is a common constituent of the heavy concentrates from the Waki River at its mouth in Lake Albert.

The dark mica has clearly been introduced subsequently by solutions which, in some instances, have also caused cloudiness in the otherwise universally water-clear felspars of the charnockite series. The variety of mica is highly ferruginous and appears to be lepidomelane. It is black (in a bromoform concentrate), is intensely pleochroic in shades of very deep mahogany to chestnut brown, and is pseudo-uniaxial. The pleochroism of this dark mica is characteristic and enables it to be recognized in many rocks from along the Bunyoro scarp hinterland, to which neighbourhood it is confined.

North Bank of River Kafu.—We now move further back into the scarp hinterland and compare the rocks of the charnockite series and gneisses southwards from Kigarobya to the north bank of the River Kafu in the area mapped by Dr. K. A. Davies.

Of specimens collected by Mr. Simmons from south of Kigarobya, about 10 miles from the escarpment, while some show little or no disturbance others are intensely sheared and mechanically foliated. Dr. Davies' specimens of the charnockite series and granitic gneisses from the north bank of the River Kafu, south of Hoima, distant about 20–25 miles from the escarpment, show much less marked signs of post gneissose-crystallization mechanical disturbance. From these facts it would appear that the effects become much less marked about 25 miles east of the escarpment.

Country Further to the South-West.—A specimen from near the crossing of the Fort Portal Road over the River Nkussi, at a point about 20 miles back from the nearest part of the rift escarpment (near the southern end of Lake Albert), tells a similar story. It is an acid member of the charnockite series which has been sheared subsequent to crystallization and secondary dark mica of the usual shades of mahogany and chestnut brown has been produced at the same time as the shearing. The felspars of the rock are clouded, an unheard-of thing for the charnockite series in any part of the world, so that it is clear that solutions have also played a part. Other specimens from this neighbourhood confirm this interpretation.

Western Side of Lake Albert Depression.—The writer has no data from the Belgian Congo, but a petrographic study of the extensive collection made by Mr. Simmons of the charnockite series and associated gneisses of the West Nile District of Uganda has yielded some relevant facts. The rocks of the charnockite series in this district, which is adjacent to the northern end of the western side of Lake Albert, have in many places suffered from the effects of dynamo-metamorphism. The intensity of this metamorphism, as represented by the collection, increases in a general kind of way

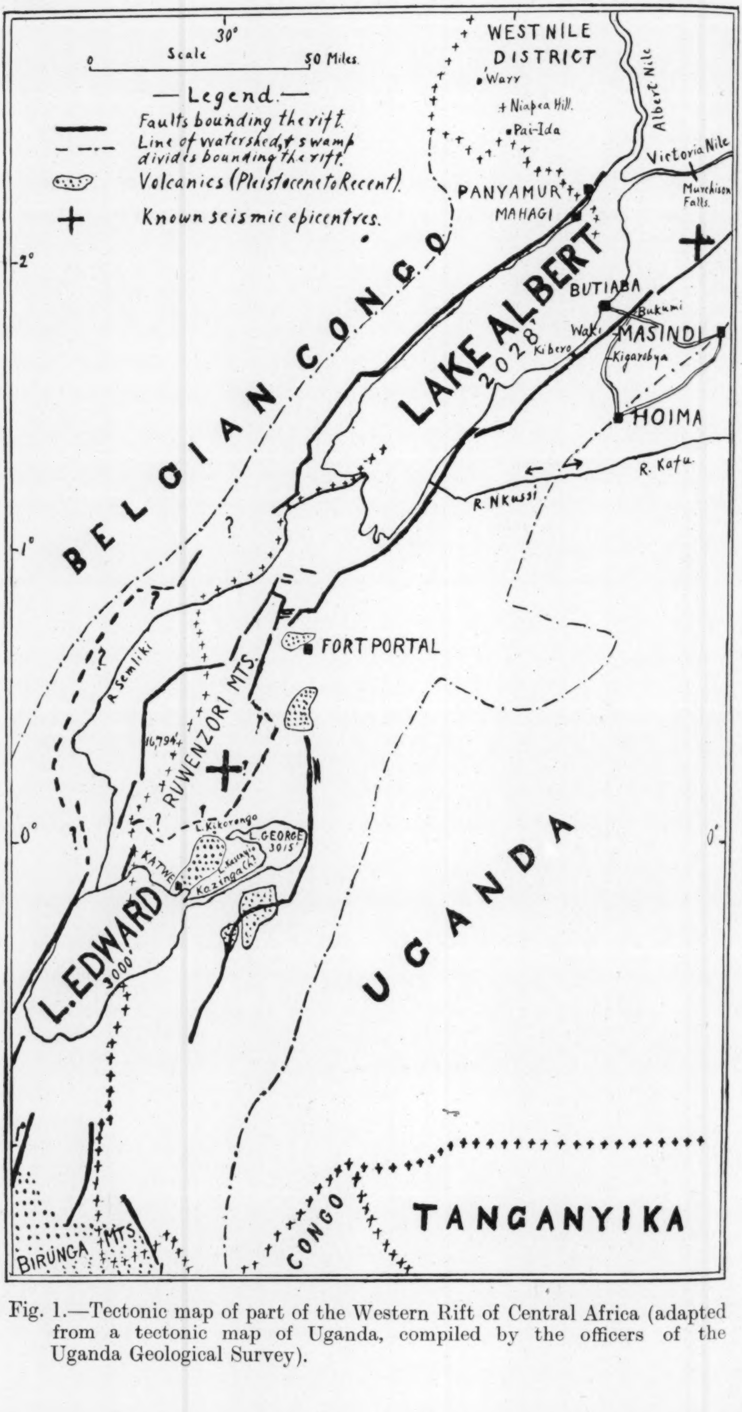
30°
Scale
0
50 Miles.
—Legend.—
Faults bounding the rift.
Line of watershed, + swamp divides bounding the rift.
Volcanics (Pleistocene to Recent).
Known seismic epicentres.
WEST NILE DISTRICT
Warr
Niapea Hill.
Pai-Ida
Albert Nile
Victoria Nile
Murchison Falls.
PANYAMUR
MAHAGI
2°
BELGIAN CONGO
LAKE ALBERT
2028'
BUTIABA
Bukumi
Waki
MASINDI
Kibero
Kigarobya
HOIMA
R. Kafu.
R. Nkussi
1°
?
FORT PORTAL
R. Semliki
RUWENZORI MTS.
16,794'
L. Kikorongo
L. GEORGE
3015'
0°
KATWE
L. Kasenyia
Kazinga Ch.
L. EDWARD
3000'
UGANDA
BIRUNGA MTS.
CONGO
TANGANYIKA

Fig. 1.—Tectonic map of part of the Western Rift of Central Africa (adapted from a tectonic map of Uganda, compiled by the officers of the Uganda Geological Survey).

towards the south as the northern end of the rift valley faults are approached. Thus from Niapea Hill, between Warr and Pai-ida, there are two specimens of mylonite in which are developed garnet and fuchsite. Between Niapea and Pai-ida, remarkable garnet-amphibole-pyroxene-leptynites are developed and in some of these the garnet crystals are also remarkable for their size, particularly between Pai-ida and Erusi on the Belgian Congo border near Mahagi.

II. RELATION OF PETROLOGICAL EVIDENCE TO TECTONIC THEORIES.

The petrographical study of the aforementioned rocks on the Uganda margins of the Lake Albert Depression shows them to be all of the plutonic metamorphic type together with members of the charnockite series. At some time subsequent to the cessation of conditions of plutonic metamorphism, shearing movements have been imposed upon them with consequent micro-brecciation and granulitization, passing into mechanically foliated and thoroughly mylonized types. At the same time there is evidence of solutions impregnating many of the rocks, introducing a secondary dark mica, and causing cloudiness in felspars of the charnockite series of Bunyoro. It is clear that these solutions came in at the time of the shearing movements.

The degree of this disturbing influence appears on both sides of Lake Albert to be related to the distance of each specimen from the nearest rift scarp. Furthermore, the secondary amphibole [1] in some of the rocks in the immediate neighbourhood or within a few miles of the rift scarp is of a distinctly sodic type. Likewise the secondary dark mica introduced during the shearing appears to be lepidomelane. Now the writer's chemical analyses show that the rocks so affected all belong to the calc-alkali series, in fact according to the classification recently proposed by M. A. Peacock (1) [2] they fall just on the border line between the calc-alkali and calcic divisions. These secondary minerals of alkalic affinities have evidently been introduced by solutions at the time of the shearing movements and alkaline rocks are only known to occur in East Africa during Tertiary to Recent times. In fact in the country bordering the Western Rift alkaline volcanic rocks are only known from Mid-Pleistocene to Recent times. On these grounds, therefore, it is reasonably certain that the disturbing influence was none other than the orogenic movements giving rise to the formation of the Western Rift. The phenomena here described are not compatible with tension, but on the contrary they are precisely those to be expected from compression, shearing, and upthrusting, combined with some impregnation by solutions from a magma alkaline in character.

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[1] Owing to the acicular grains of the mineral being frequently thinner than the micro-section, or compensating one another, it has not been possible to determine its extinction angle. It has negative sign of elongation, pleochroism X bluish-green, Y greenish-blue, Z pale greenish-blue, and is therefore a sodic amphibole.

[2] Figures in parentheses refer to Bibliography at end of article.

The specimens here referred to represent detailed collecting over a belt extending for 15 miles along the escarpment of the Lake Albert Depression and back for at least 10 miles into the hinterland. This, together with the adjacent area between Hoima and the River Kafu, is the only strip of the eastern scarp hinterland which has been subjected to intensive collecting. Nevertheless, there is ample evidence to show that these effects continue to a distance of quite 25 miles back from the Bunyoro escarpment. Moreover, the evidence of specimens from scattered localities further south-west along the eastern scarp, and some at distances of 20 miles from it, strongly suggests that this belt of intense shearing runs along the entire length of the scarp on the Uganda side. The evidence from the West Nile District suggests that the zone of intense shearing on the Congo side may be even wider than that in Bunyoro and Toro. Thrusting and shearing on such dimensions must involve lateral compression on an enormous scale.

The Nandi Escarpment, to the south-east of Mount Elgon, was discovered by Ödman (2, p. 89) to have " a development of highly sheared gneisses and even mylonites ", which he considered to indicate a fault-line. He states that " when approaching the escarpment from the west one observes in some places an increasing foliation and schistosity " and again " only along the fault-line of the Nandi Escarpment the rocks are locally turned into gneisses, schists, and even mylonites ". This is of particular interest inasmuch as Wayland considers the Nandi Escarpment to be one of the fracture lines associated with the rift (3, p. 340) and to be older than the peneplanation (3, p. 341).

It was in 1921 (4) that Wayland first suggested the Lake Albert Depression was brought about by lateral compression consequent upon thrust exerted by Gondwanaland during its subsidence [1] and the pressure was regarded as acting from one side only (the south-east) (3, p. 335 and 336). Later (3) the mechanism was modified and explained in detail. Wayland's theory in its revised form invoked a rift block forced to sink by compression while the sides of the rift bulged upwards owing to pressure consequent upon resistance of the rift block to depression (3, p. 351). This pressure also gave rise to upthrusting (3, see Fig. 2) along the scarps. The presence of a fault which curves upwards in the scarp cliff near Kibero and which is to be interpreted as a thrust rising surfacewards has been noted by Bailey Willis (3, p. 341 and 5). Bailey Willis states that the rocks on the margin of this thrust are mylonite (5, p. 217). The present writer has also noted considerable thicknesses of highly sheared and mylonized rocks dipping inwards under the scarp on the Masindi Road where it climbs the scarp behind Butiaba. A photograph of these appears in Pl. XXXVIII, Fig. 2.

Bailey Willis, in his *Living Africa* (5, pp. 287–309) has put forward the suggestion that in the saucer-shaped area approximately 450 miles across, which he styles the Victoria Disc, outward lateral pressure has been exerted. Around the outer rim of this saucer-shaped disc are upraised blocks and erupted molten masses as the result of the lateral pressure exerted around that margin.

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[1] Wayland's revised theory dispenses with Gondwanaland.

The petrological evidence of large scale lateral compression and shearing described above from the rocks of the Bunyoro and West Nile Districts of Uganda, as well as Ödman's evidence in the Nandi Escarpment, all fit in very well with these theories of Wayland and Bailey Willis. The effects of conversion of hypersthene to garnet, granulitization, brecciation on a microscopic scale, and mylonization developed over such wide areas cannot be merely superficial and they would appear to require the removal of a considerable amount of overburden before they could be exposed at the surface. Taken in conjunction with the thickness of the deposits in the Lake Albert Depression[1] this new evidence adds further weight to the suggestion made by Hirst (7, p. 43) and by Wayland (3, p. 342) that the tectonic activity which gave rise to the Lake Albert Rift in Tertiary and Quaternary times is no new feature. In fact, Hirst went so far as to suggest that the Karagwe-Ankolean beds of Bunyoro were deposited in an ancient rift.

In the course of three years of petrological studies of the plutonic rocks of Uganda it has become increasingly evident to the writer that over the country as a whole denudation has gone down very deeply indeed so that it is an excellent region for the study of those phenomena which have been styled "plutonic metamorphism" (8). During the last year the writer's work has been directed mainly to the charnockite series and associated gneisses which occur over much of the northern half of the Protectorate. As work on these has proceeded, increasing petrographic evidence has been collected pointing to growing intensity of metamorphism at depth until the conditions amounted to those of plutonic metamorphism. There is now considerable evidence, petrological and chemical, as well as that obtained in the field, which goes a long way towards proving that the charnockite series themselves are the products of intense plutonic metamorphism and even palingenesis.

As the degrees of plutonic metamorphism advance so the constituent minerals of the plutonic rocks recrystallize and become more and more equigranular in texture. Then gradually they become aligned, in some instances apparently owing to vertical pressure. The conditions give every indication that at depth in this part of the world during earlier geological history crystal growth was in a horizontal direction and so we come nearer to Bailey Willis' theory that the driving force which has caused the outward lateral pressures from the Victoria Disc is due to the expansion and crystalline rearrangement of the underside of the disc at depth. Bailey

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[1] Wayland considers that 2,000 feet is a decidedly conservative estimate (6, p. 25).

Willis contends (5) that at depth in undisturbed portions of the earth's crust the vertical pressure is so great that crystal growth is more easy in the horizontal direction than any other. When, however, they have been squeezed to the point that they release the molecular forces they themselves exert a greater horizontal pressure than that of the load. Crystals up against which this pressure comes in neighbouring areas will then grow vertically if they yield at all. Over regions where crystals grow horizontally basins develop and where crystals grow vertically continents arise. In this way the forces due to crystalline rearrangement under the Victoria Disc have thrust up the plateaux along the edges of the Albert and Tanganyika troughs and pushed up the mass of Ruwenzori while the rift blocks have gone down.

Thus in the writer's opinion the petrological evidence in the plutonic and basement rocks of the peneplain of Uganda, as far as he has studied it, strongly supports the compressionist view of the formation of the Lake Albert Rift and tends to give some support to Bailey Willis' views of the origin of the forces giving rise to those compressional movements.

PART III. RELATION BETWEEN THE VOLCANIC ROCKS AND RIFT VALLEY TECTONICS.

When we appeal to the products of the volcanic activity which has broken out along the Western Rift the petrological evidence is conflicting.

Starting from the northern end of Lake Albert and working southwards along the Western Rift, so far as has been discovered, there has been no volcanic activity until we reach the Fort Portal district, in that unstable corner of the Uganda peneplain (average altitude here is about 5,000 feet) bordered on the north and south by the sunken areas of Lake Albert (2,000 feet approximately) and Lake George (3,000 feet), and to the west by the northern part of the upthrust block of the mighty Ruwenzori Range—50 miles long and rising to peaks of 16,000 and 17,000 feet. These volcanic fields to the east and south-east of Ruwenzori consist almost wholly of vents of the explosive and caldera type surrounded by tuffs. The petrology of the tuffs, bombs, and ejected blocks of this volcanic field have been described in detail by Holmes and Harwood (9), while other work on this area has been published by A. D. Combe (10) and the writer (11). Holmes and Harwood have shown the rocks to be melilite-basalts, melanocratic varieties of potash-ankaratite and leucitite ; most of which are referred to as potash-ankaratite or leucite-ankaratite ; leucitite and olivine-leucitite ; also several types of pyroxenite which constitute a well-defined suite of subvolcanic rocks. This activity commenced towards the close of the Kaiso lacustrine period of the Western Rift (Lower to Middle Pleistocene) and continued to late Pleistocene and possibly even into recent times.

The discovery by the writer of recent tufa cones in the craters of Katwe and Kasenyi near the Kazinga Channel, of springs at Lake Katwe charged with the carbonates and sulphates of sodium and potassium as well as reeking with sulphuretted hydrogen (11, pp. 12–16), and that the waters of Lakes Katwe, Kasenyi, and Kikorongo all have this composition, is evidence of the fact that this region is still in the decadent phases of volcanic activity. Quite recently (12) Worthington and Beadle have demonstrated the existence of a well marked thermocline at depths between 40 and 60 metres in Lake Edward, and have ascribed this to volcanic activity.

Thirty to fifty miles south of Lake Edward is the great Birunga volcanic field, the north-eastern corner of which (Bufumbira) lies within the Uganda Protectorate. This is probably the largest mass of leucite-bearing rocks in the world, and A. D. Combe and W. C. Simmons have given summaries of their work on this area in the Annual Reports of the Geological Survey of Uganda for the years 1925–9. A preliminary account of the area has been given by Simmons (13) and a memoir on the subject is promised. Several of the volcanoes of the district are still active. The lavas are described by Simmons (13, pp. 492–9) as being in the main leucite-basanites and leucitites, with also leucite-basalts, enstatite-andesites, and limburgites.

In sharp contrast with the potassic lavas of the Western Rift are the predominantly sodic types of the Eastern Rift in Kenya. Then again the enormous outpourings of Mount Elgon described by Ödman (14), its outliers Walasi, Nkokonjeru, and continued northwards in the chain of volcanic hills formed by Mt. Debasien, the Napak-Kamalinga Group, Mt. Moroto, Koten Hill, and Mt. Toror are all of the alkaline type and associated with the Lake Rudolf zone of the Eastern Rift. In Elgon the rocks are for most part nephelinites and are all dominantly sodic. Some specimens from Koten Hill, Karamoja, collected by Mr. Wayland and examined by the writer prove to be nepheline-phonolite. This rock consists of large phenocrysts of anorthoclase and nepheline with somewhat smaller, partly resorbed, crystals of barkevikite, aegirine-augite and occasional colourless titanite in a fine-grained groundmass made up of small felspar laths with aegirine-augite and nepheline. At Lokopoi Hill, in the Napak-Kamalinga Group, there is a nepheline-syenite, approximating to ijolite, which in places carries schorlomite crystals up to an inch across. There are several occurrences of nepheline-syenites of various kinds in the neighbourhood of Mt. Elgon, as for instance in the Siroko Valley and at Tororo, while the writer has observed barkevikite on numerous occasions in the nephelinites. Although the rocks of the other hills mentioned have not yet been examined petrographically it is highly probable that they will all turn out to be dominantly sodic rocks.

The position is, then, that in the Western Rift we have volcanics which are dominantly potassic while in eastern Uganda, and in Kenya, those associated with the Eastern Rift are in the main dominantly sodic. The Eastern Rift is generally accepted as a tension phenomenon (even by some of the compressionists), while there is a growing school which holds that the Western Rift is a compressional feature. Is there any tectonic explanation for these contrasted types ? Confronted with this question Prof. Holmes (9, p. 442) replied that according to the hypothesis proposed in his joint paper (9) the rocks relatively rich in potash require differentiation under conditions of higher magmatic pressure than the sodic ones ; evidence for this differentiation was, he thought, afforded by the spectacular uplift of Ruwenzori, corresponding to which there was nothing comparable on the eastern side of Lake Victoria. Dr. D. R. Grantham has, however, pointed out (9, p, 441) that the Western Rift also contains sodic rocks, as, for example in the Rungwe-Mbeya area to the north of Lake Nyasa, from which he deduces that the type must be a product of local tectonics, not of Eastern or Western Rifts.

The potassic and sodic nature of the Western and Eastern Rifts is also reflected in the composition of the waters of the saline lakes. Whereas Magadi, Natron, and other lakes associated with the Eastern Rift are characterized by high contents of sodium carbonate, the lakes of Busongora (south-east of Ruwenzori) contain also very appreciable amounts of potash salts. The writer's analyses of these saline waters show that the content of metallic potassium may amount to 8 per cent of the total salts (11, p. 14).

Thus we see that while the evidence of the basement rocks of the Uganda peneplain is tolerably clear in favour of compression, that of the volcanics is not so simple. To some the association of alkaline rocks with compressional movements may not be acceptable, but in the Western Rift there appears to be a marked connection between potassic types and compression. Indeed, in the Andes of Southern Mendoza, Argentina, Backlund (15) observes that " Every cycle (of orogeny) beginning with andesites (or granodiorites) of relatively acid composition ends with rocks of decreasing silica content and that each cycle is marked by a late afterbirth of (dyke) rocks showing increasing characteristics of an alkaline suite (sparse felspathoids, aegiritic-augite, etc., mica lamprophyres also) ".

A factor of importance in this controversial subject is that, as was shown in Part I, there is evidence that the movements giving rise to the Lake Albert Depression commenced early, whereas the volcanic episode in the Western Rift was definitely late (Middle Pleistocene to Recent) and, in the Birunga volcanoes, is still in progress. A large, and probably the greater, part of the volcanic outbursts associated with the Western Rift appears to be subsequent to the main rifting. These facts are in accord with the generalizations of H. G. Backlund (15) in his recent review of the mode of intrusion of deep-seated alkaline bodies. He observes : " It may be pointed out that the position of all the most typical alkaline bodies lies within the old stable areas and that they are later in their *mise-en-place* than its structural deformation." Again he says: "The alkaline intrusions piercing through the very stable areas may be a sort of epeirodiatresis, a perforation of stable continental areas."

It may perhaps be questioned by some whether the backbone of Africa is yet stable in view of the frequency of earthquake shocks. This seismic activity, as far as Uganda is concerned, appears in the main to be connected with the Western Rift. One epicentre has been located in Ruwenzori by Simmons (16) and another is considered by the writer to be situated near the north-eastern end of Lake Albert (17). Vibratory tremors are common enough, indeed, in 1929, 120 shocks believed to have come from the Ruwenzori epicentre were recorded on the seismometer at Entebbe distant about 170 miles (17). Other centres in Kenya are the eastern side of the Eastern Rift near Nairobi, and the coastline around Malindi, north of Mombasa. With possibly the sole exception of the Fort Hall earthquake of 1928, none of the East African shocks subsequent to British occupation has been sufficiently strong to cause appreciable damage to buildings and they appear to be in the nature of slight readjustments in a now comparatively stable area.

The data here presented were obtained by the writer during his service on the Geological Survey of Uganda, or on rocks collected by that Department (and subsequently studied by him at the Imperial College of Science and Technology), and he is indebted to the Director, Mr. E. J. Wayland, for permission to publish these results. The assistance received from a grant made by the Royal Society is also gratefully acknowledged.

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EXPLANATION OF PLATES XXXVI–VIII.

Figures 1–5 are all taken with crossed nicols and a magnification of 15 diameters.

Plate XXXVI.

Fig.

1.—Nine miles from the Lake Albert escarpment above Butiaba. Spec. G. 69. Gneiss showing a highly mylonized form of " mortar-structure ". Most of the felspar granules display a finely microscopic form of microperthitic twinning with undulose extinction which is peculiar to these rocks bordering the Bunyoro scarp of the Lake Albert Depression. Much of the material appearing black on the left-hand margin is acicular sodic-amphibole.

2.—Spec. G. 70. Nine miles from the Lake Albert escarpment above Butiaba. Gneiss showing granulation, shearing, mylonization, and impregnation by alkalic solutions. Four or five felspar granules on the left, remnants of one crystal, display cracks parallel to the direction of shearing and appear black on account of the development of sodic-amphibole along them. Groundmass of mylonitic debris in which much acicular sodic-amphibole is visible oriented parallel to the direction of foliation. The usual very fine twinning occurs in all the original felspar.

Plate XXXVII.

1.—Spec. G. 71. Eight miles from the Lake Albert escarpment above Butiaba. Felspathic gneiss showing foliation due to shearing. The crystals are all shattered and are separated from one another by channels of mylonitic debris. The felspar displays very finely microscopic twinning.

2.—Spec. G. 71. Same locality as last. Felspathic gneiss with a thrust plane (picked out by needles of sodic-amphibole) traversing the section diagonally from bottom-left to top-right. Cracks in the adjacent felspar are parallel to the thrust. Apart from shattered remnants of large felspar crystals, most of the field is occupied by mylonitic debris. Approach to a mylonite.

Plate XXXVIII.

1.—Spec. G. 73. A few hundred yards from the top of the main escarpment above Butiaba. A thorough mylonite with few remnants of the original felspar.

2.—Mylonitic gneisses dipping into the scarp face of the Lake Albert Depression below Bukumi Camp on the Masindi Road about eight miles from Butiaba. The cliff face here shown is a subsidiary one oblique to the direction of the main scarp face.

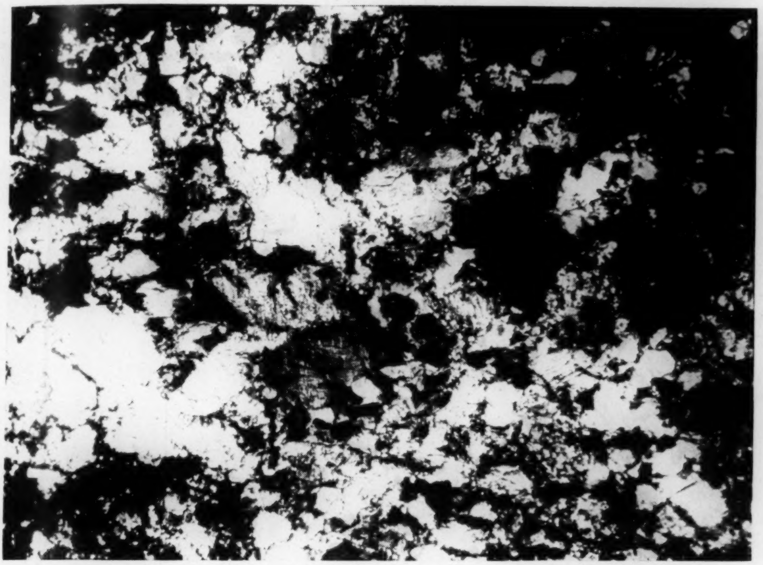
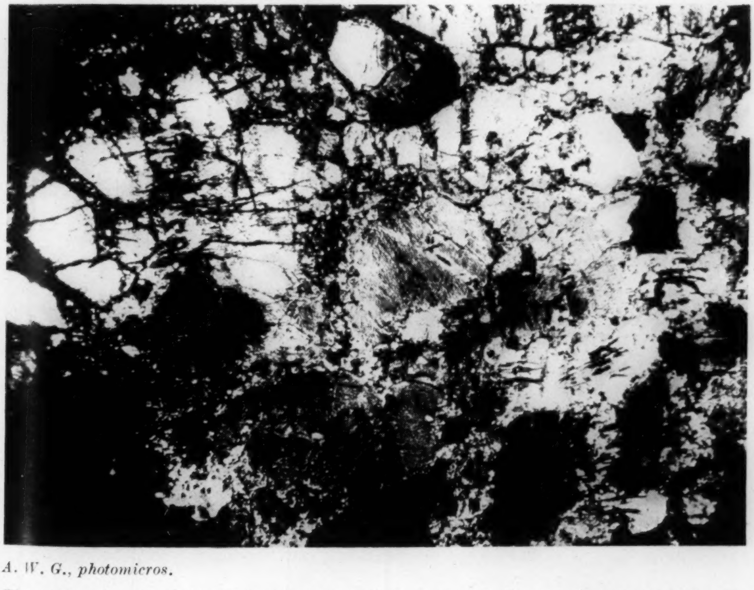


FIG. 1.



A. W. G., photomicros.

FIGS. 1 AND 2.—ANCIENT GNEISSES FROM THE LAKE ALBERT ESCARPMENT SHOWING COMPRESSIONAL FEATURES ACCOMPANIED BY THE DEVELOPMENT OF ACICULAR SODIC AMPHIBOLE.

[*To face p.* 510.

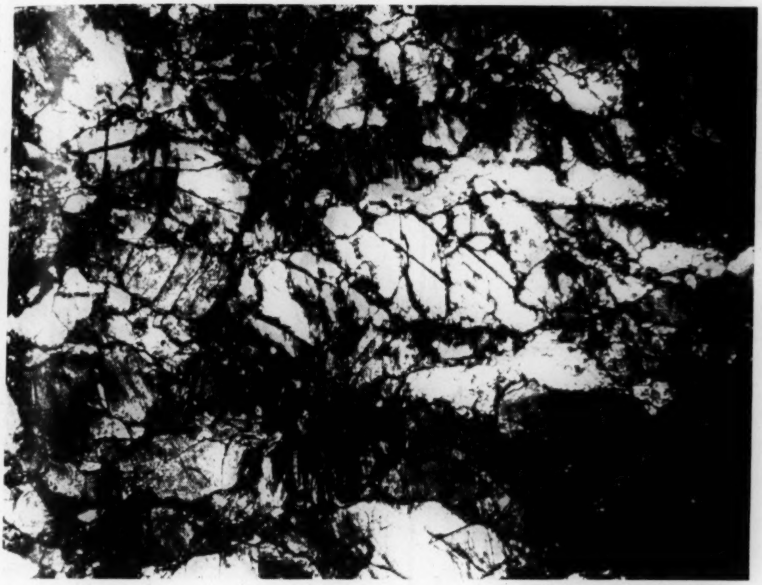
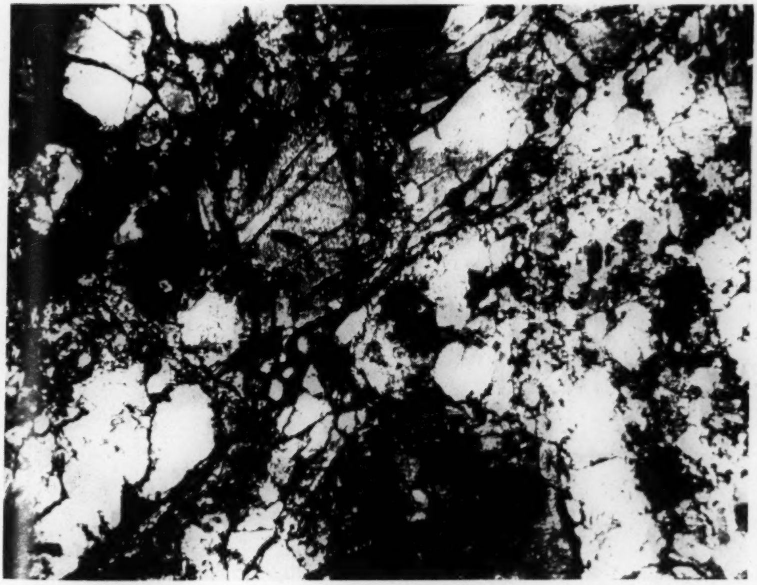
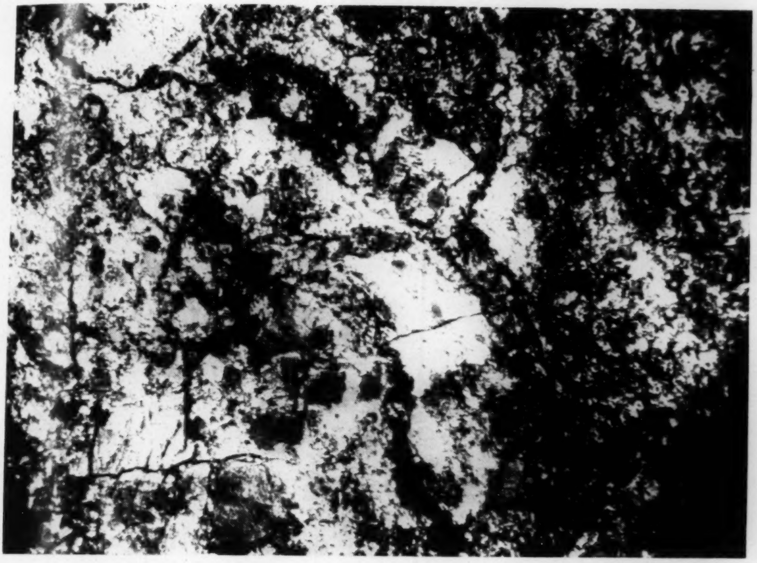


FIG. 1.—GRANULATION AND FOLIATION DUE TO SHEARING.



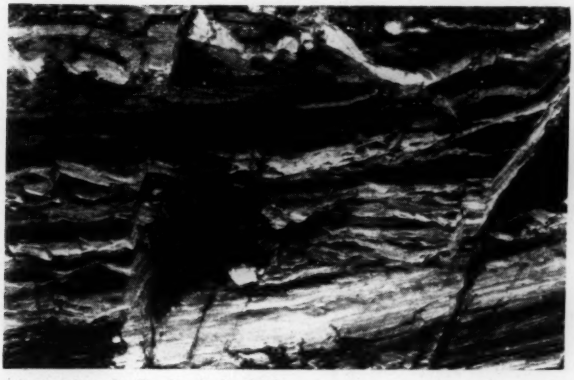
A. W. G., photomicros.

FIG. 2.—MICROSCOPIC THRUST PLANE ACCOMPANIED BY MYLONIZATION.



A. W. G., photomicro.

FIG. 1.—MYLONITE FROM TOP OF ESCARPMENT ABOVE BUTIABA.



(From photo. by Dr. K. A. Davies.)

FIG. 2.—MYLONITIC GNEISSES IN THE SCARP FACE ABOVE BUTIABA.

New Miocene Faunas from Cyprus.

By F. R. Cowper Reed, Sc.D., F.G.S.

An interesting collection of Tertiary fossils has recently been sent me for determination by Mr. C. P. Manglis, Manager of the Mitsero mines in Cyprus, who has collected them from the neighbourhood of these mines. Mitsero village stands near the head of a valley running down the north side of the Troodos mountains to the plains of Morphou and is described by Messrs. Cullis and Edge (1, p. 38)[1] as standing on volcanic rocks close to the junction of the pillow-lavas with the overlying marls and limestones, while " behind it is a bold sedimentary escarpment breached by the valley just mentioned and culminating in Koroni Mountain (2,140 feet), 1½ miles to the west-north-west ". The Koronia Limestone, the outcrop of which on the Evrykou road the author visited in 1929 (2, p. 443), occupies the top of the escarpment, as shown on a map sent to me by Mr. Manglis of the immediate district (scale, 1 : 10,000) from the village of Kato Moni on the north-west to the village of Mitsero on the south-east. The position and age of the Koronia Limestone have been uncertain owing to the lack of definite fossil evidence, though the author (2*a*, p. 251) was inclined to put it in the Miocene rather than the Pliocene on the strength of a species of *Cerithium* which he discovered in it. The majority of the fossils in Mr. Manglis's collection come from this limestone and provide ample evidence of its Miocene age.

From two localities in the neighbourhood of the Mitsero mines, Mr. Manglis has been fortunate to find also the Clypeaster horizon, apparently corresponding to that discovered nearly thirty years ago by Miss Bate at Cape Pyla and referred by Dr. Bather in 1905 to the Helvetian on the strength of the occurrence of the species *Clypeaster altus* var. *portentosa*.

The lowest stage of the Miocene (Idalian) series in the island occurring below the great mass of white chalky limestones and marls which constitutes the main part of the Miocene has been described (2*a*, p. 244) as consisting of greenish and greyish marls with occasional beds of gypsum. It is proved that beds of similar lithological character have been pierced in the drill-holes at certain localities on and around Koroni Hill below the Koronia Limestone, but the absence of the white chalky limestones in the bore-holes is unexplained. Whether the latter have thinned out or are partly represented by greenish clays or owe their absence to tectonic causes cannot yet be stated; the fossils from the clays are unfortunately very rare or only generically determinable in most cases, so that their precise age and horizon are uncertain. But Blanckenhorn (4, p. 595) has described that in the Miocene of the Second Mediterranean Stage in north Syria the limestones may thin out or be more or less locally replaced by clays and marls with intercalated masses of gypsum, and in view of the close structural and faunistic relations of the mainland and Cyprus we may conjecture that the same irregularity and variation in the succession occurs in both areas.

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[1] Figures in parentheses refer to References at end of article.

List of Localities.

K (Koronia Limestone).

(1) 3 metres below surface in shaft 160 metres on west of Kreados trigon. point, near Agrokipia village.
(2) Zenia Hill, near Ayia Marina village.
(3) Kotaphi Hill, near Agrokipia village.
(3*a*) Summit of Kotaphi Hill.
(3*b*) Kotaphi Hill, a little below summit.
(4) Summit of Kavasi Hill, near Ayia Marina village.
(5) Near drill hole No. 1, near Ayios Eliophotes village.
(6) Lower part of " calcaire semicristallin " near Ayios Eliophotes village.
(7) Trimythoudia, 800 metres N.W. of Mitsero village.
(8) Summit of Koroni Hill, near drill hole No. 10.
(9) 300 metres S.S.E. of Kavasi summit, near Ayia Marina village.
(10) Koroni-Trimythos Hill, near drill hole No. 17.
(11) 500 metres north of Koroni Hill, near Mitsero village.
(12) Trigonometrical point of Kreados, near Agrokipia village.
(13) 250 metres N.W. of Trimythos trigon. point.
(14) 150 metres S.E. of Kato Moni village on footpath leading to summit of Koroni Hill.

A. 450 metres N.E. of Trimythos trigonometrical point, between Mitsero and Kato Moni villages.
B. 1. 300 metres south of Kavasi summit, near Ayia Marina village.
B. 2. 400 metres east of Agrokipia village.
C. Drill hole No. 19, N.E. of Ayios Eliophotes village.
20 metres below surface.
57 ,, ,, ,,
67 ,, ,, ,,
75 ,, ,, ,,
78 ,, ,, ,,
85 ,, ,, ,,
99 ,, ,, ,,
108 ,, ,, ,,
115 ,, ,, ,,
127 ,, ,, ,,
145 ,, ,, ,,
D. Drill hole No. 18, N.N.W. of Ayios Eliophotes village.
125 metres below surface (greenish sandy clay).
149 ,, ,, ,, (hard chalky limestone).
E. Drill hole No. 20 (725 metres N.E. of drill hole No. 1 on north side of Koroni Hill).
5 metres below surface.
36 ,, ,, ,,
40 ,, ,, ,,
F. Near contact of Flysch and pillow lava at union of Argos potamos and Argaki tou Paleomylou near Asproghia village, Paphos district.
G. Mavrovouni near Lefka village (contact of sediment and pillow lava).
H. Drill hole No. 10, 60 metres below surface, Koroni Hill.
I. 136 feet below surface in water shaft, 1½–2 miles N.W. of Peristerona village.
J. 150 metres west of Lambodhou ruins near Mitsero village.

LITHOLOGICAL CHARACTERS OF THE ROCKS.

The Koronia Limestone is usually a tough, compact, very hard semicrystalline rock with a splintery subconchoidal or granular fracture, and is generally creamy white in colour. But it may be pale pinkish, greenish, or buff coloured, and in some cases (as at localities (3), (11), and (14)) it is less compact, being coarsely granular and carious, or in places oolitic, with small patches of tough, fine-grained, massive semicrystalline limestone occurring irregularly in it. It is frequently composed of masses of broken shells and casts of small gastropods. Most of the fossils in this limestone consist only of internal casts or impressions of the exterior, and are generally in an imperfect condition.

The rock from locality A, 450 metres north-east of Trimythos trigonometrical point, is a softer limestone, finely granular and not semicrystalline, but probably it forms part of the same calcareous deposit as the typical Koronia Limestone, though the fossils are somewhat differently preserved in it. It is buff in colour and inclined to crumble easily.

The fossils from locality B 1, 300 metres south of Kavasi summit, near Ayia Marina village, occur in a soft greenish or yellowish sandstone. The same rock occurs at locality B 2, 400 metres east of Agrokipia village.

All the fossils from locality C occurring at various depths in Drill-hole No. 19 are contained in greenish clays or sandy clays or marls, except at the first level of 20 metres, where the rock is a rather soft, white, chalky limestone.

The drill hole No. 18 at D penetrates at 125 metres a greenish sandy clay, but at 149 metres it pierces a hard, white, chalky limestone.

The drill hole No. 20 at locality E pierces at 5 and 40 metres a crumbly, gritty, soft, buff coloured limestone much like that of A. But at 36 metres the limestone is pale grey in colour, compact, and semi-crystalline and is lithologically similar to that occurring near drill hole No. 1 at Ayios Eliophotes village, and referred to the Koronia Limestone.

The single specimen from locality F is a tough greenish clay with sub-conchoidal fracture.

From locality G the two small specimens are in a soft, greenish, clayey sandstone.

The rock of locality H from drill hole No. 10 is a soft, gritty, yellowish or buff coloured sandstone, somewhat calcareous, with the fossils occurring rather abundantly as casts with a ferruginous stain.

The fragmentary vertebrate remains (Chelonian) from locality I occur in a very soft, friable, greenish sandstone. Dr. W. E. Swinton has kindly examined them and determined the genus.

The three specimens of corals from locality J occur in grey limestone in a much weathered condition. Dr. Stanley Smith, who has kindly examined them, informs me that only one specimen is determinable and this belongs to the genus *Heliastraea*.

List of Species from the Koronia Limestone.

(The numbers in parentheses refer to the localities at which the fossils have been found.)

Ostrea vestita Fuchs (4).
,, sp. (1).
Exogyra sp. (1).
Pecten multistriatus Poli (1), (7), (10), (14).
,, *submalvinae* Blanck. (1).
,, cf. *praebenedictus* Tourn. (1).
,, cf. *incrassatus* Partsch (1).
,, cf. *concavus* Blanck. (4).
,, sp. (1).
Spondylus imbricatus Micht. (1).
Radula lima L. var. *dispar* Micht. (7), (14).
Arca Noae L. (14).
,, (*Barbatia*) *barbata* L. (1).
,, (*Anadara*) *diluvii* Lk. (1).
,, (*Fossularca*) *lactea* L. (4).
Pectunculus [*Axinaea*] *textus* Duj. (1), (4).
Limopsis (*Pectunculina*) *anomala* Eichw. (4).
Cardita cf. *transversalis* Desh. (6).
,, sp. (3), (9).
Cardium multicostatum Br. (1).
,, *Andreae* Duj. var. (1).
,, *edule* L. var. *sublamarcki* D. and D. (1).
,, (*Pseudocardita*) sp. (1).
,, sp. (3), (2).
Cardilia cf. *Michelottii* Desh. (1).
Chama gryphoides L. (14).
,, sp. (7), (9).
Lucina (*Dentilucina*) sp. (15).
,, (*Megaxinus*) sp. (1).
Jagonia reticulata Poli. (12).
,, cf. *pecten* Lk. (6).
Venus (*Timoclea*) *ovata* Penn. (10).
,, (*Clausinella*) cf. *Amidei* Menegh. (14).
,, (,,) *Basteroti* Desh. (1).
,, sp. (1).
Astarte cf. *solidula* Desh. ? (11).
,, ? sp. (9).
Meretrix (*Amiantis*) cf. *islandicoides* Lk. (1).
Tapes vetulus Bast. (1).
,, *geographicus* L. (14).
Capsa abbreviata Duj. (11), (13).
Circe (*Gouldia*) *minima* Montg. (1).
Septifer oblitus Micht. (36).
Lithophagus lithophaga L. (7), (10), (12).
Tenagodes anguinus L. var. *parvula* Sacco (14).
Haliotis tuberculata L. (14).
Trochus patulus Br. (1), (9).
,, *rotellaris* Micht. (7), (9).
,, cf. *granosus* Bors. (10).
,, cf. *Borsoni* Micht. (7).
,, cf. *turbinatus* Born. (9).
,, ssp. (1), (6), (9), (10), (11), (13).
Capulus ungaricus L. (14).
,, sp. (9).
Fissurella cf. *italica* Dep. var. *reticulina* Risso (1), (4).
Turritella turris Bast. var. (4).
,, *vermicularis* Br. ? (4).
,, *subangulata* Br. var. (4).
Cerithium granulinum Bon. var. (13).
,, *koroniense* sp. nov. (2).
,, cf. *dertonense* May. (9).
,, cf. *procrenatum* Sacco (9).
,, cf. *tauroacrenatum* Sacco (9).
,, cf. *tauroconicum* Sacco (9).
,, cf. *taurinium* Bell (1), (9).
,, cf. *laevisubuloides* Sacco (9).
,, cf. *tauroprecedens* Sacco (9).
Nassa ? sp. (6).
Small indet. gastropods (1), (4), (6), (10).
Serpula sp. (4).
Cidaris sp. (8), (13).
Psammechinus sp. (1), (10).
Prionastrea ? sp. (14).
Globigerina sp. (1), (3*a*), (14).

Lists of Fossils from other Beds and Localities.

(A) 450 metres north-east of Trimythos trigonometrical point between Mitsero and Kato Moni villages.

Ostrea sp.
Pecten cf. *Larteti* Tourn.
,, cf. *gloriamaris* Dub.
,, cf. *Ficheuri* Brives.

Hinnites cf. *Brussonii* De Serr.
Pectunculus [*Axinaea*] *inflatus* Br.
„ [„] *cor* L.
Venus (*Timoclea*) *ovata* Penn.
Cardium papillosum Poli.
Cardita cf. *monilifera* Duj.
Lucina (*Megaxinus*) *transversus* Brn.
Lucinopsis rupestris Br. ?
Capsa lacunosa Chemn.
Lithophagus lithophaga L.
Teredo sp.
Clanculopsis ? sp.
Turritella cf. *miotaurina* Sacco.
Polyzoan.

(B 1) 300 metres south of Kavasi summit near Ayia Marina village.
Pecten subarcuatus Tourn.
„ *ziziniae* Blanck.
„ cf. *Besseri* Andr.
„ *praescabriusculus* Font.
Spondylus crassicosta Lk.
Radula (*Mantellum*) *inflata* Chemn.
Cardium (*Discors*) *spondylioides* Von Hauer.
Chama sp.
Dosinia ? sp.
Isocardia (*Cytherocardia*) *cytheroides* May.
Strombus coronatus Defr.
„ cf. *Bonellii* Brn.
Clypeaster altus Klein var. *alticostatus* Mich.

(B 2) 400 metres east of Agrokipia village.
Clypeaster altus Klein var. *alticostatus* Mich.

(C) Drill-hole No. 19.
At 20 m. *Globigerina* sp.
At 57 m. *Dentalium* sp.
Spine of *Cidaris* ? sp.
At 67 m. *Globigerina* sp.
Nodosaria sp.
Vaginulina sp.
At 75 m. *Globigerina* sp.
Nodosaria sp.
At 78 m. Indet.
At 85 m. *Nodosaria* sp.
At 99 m. Indet.
At 108 m. *Limopsis* (*Pectunculina*) sp.
Solenastraea sp.
At 115 m. *Limopsis* (*Pectunculina*) sp.
Dentalium cf. *Michelotti* Hoern.
„ *tetragonum* Br.
Solenastraea sp.
Globigerina sp.
At 127 m. *Yoldia longa* Bell.
Dentalium sexangulum Schr. var.
At 145 m. Indet.

(D) Drill-hole No. 18.
At 125 m. *Yoldia affinis* Bell.
At 149 m. Indet.

(E) Drill-hole No. 20, 725 metres north-east of drill hole No. 1.

At 5 m. *Globigerina* sp.
At 36 m. *Tenagodes anguinus* L. var. *parvula* Sacco.
Psammechinus sp.
At 40 m. Indet.

(F) Near contact of flysch and pillow-lava near Asproghia village.
Indet.

(G) Mavrovouni near Lefka village.
Amphistegina sp.
Robulina sp.

(H) Drill-hole No. 10 at 60 metres below surface, Koroni Hill.
Pecten varius L. var.
Arca (*Fossularca*) *Gaimardi* Payr.
Isocardia cor L.
Cardita cf. *ambigua* Micht.
Cryptodon ? sp.
Fissurella cf. *costicillatissima* Sacco.

(I) 136 feet below surface in water-shaft, 1½–2 miles north-west of Peristerona village.
Trionyx (*Aspideretes*) sp. (determined by Dr. W. E. Swinton).
Viviparus (*Paludina*) sp.

(J) 150 metres west of Lambodhou ruins near Mitsero village.
Corals (determined by Dr. Stanley Smith.)
Heliastraea aff. *Humphreysi* Felix.

CONCLUSIONS.

With regard to the fauna of the Koronia Limestone as compared with that of the soft chalky limestones and white marls which constitute the typical development of the Miocene in Cyprus it is remarkable that we find no species in common. But it is probable that the limestones below Curium which the author (2*a*, p. 250) believed to belong to the top of the Idalian series and which possess a shelly facies would be found to possess a close resemblance if we knew their fauna more fully.

The rare but characteristic fossils of the chalky limestones and white marls are *Aturia Aturi* and *Ostrea cochlear*, and these are lacking in the Koronia Limestone. The peculiar echinoids are also absent. On the other hand a much more abundant and varied fauna is present composed of quite a different assemblage of species.

If we refer the chalky limestones and white marls to the Langhian or Schlier (first Mediterranean stage of Suess) and the *Clypeaster* bed which occurs at Cape Pyla and in the Koroni district at localities B. 1 and B. 2 to the Helvetian and corresponding to the Greensands of Malta, we may correlate the Koronia Limestone with the upper part of the Helvetian or possibly the Tortonian, which are frequently united under the name Vindobonian, and belong to the Second Mediterranean Stage of Suess. Probably the Upper Coralline Limestone of Malta, which likewise varies in texture and character, belongs to about the same horizon as the Koronia Limestone.

The fossils from locality H undoubtedly indicate a Tortonian age, and the arenaceous character of the bed in which they occur points to different conditions of sedimentation.

The few fossils from the clays and clayey sands in the drill-holes at localities C, D, and E, point to a Miocene rather than Oligocene age, but are hardly sufficient to fix the precise age of the beds.

The faunistic relations of these marine Miocene beds of Cyprus to those of Cilicia and north Syria described by Daus (3) and others (5) are now seen to be even closer than was stated by the author in 1930 (2*a*, pp. 242–5).

The occurrence of a sandy bed with freshwater fossils at locality I near Peristerona is of much interest, as no freshwater facies of any part of the Tertiary has previously been detected in Cyprus, although well developed on the mainland (6). Dr. Swinton, who has kindly determined the Chelonian remains, states that they are " fragments of the costal plate of a Trionychid turtle, probably *Trionyx* (*Aspideretes*) sp. This family has not so far been reported from Cyprus, but it is recorded from the Miocene of Malta and from the Miocene and later periods of Africa, Syria, and Mesopotamia ".

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(5) M. Blanckenhorn and P. Oppenheim. " Neue Beiträge zur Kenntnis des Neogens in Syrien und Palästina," *Geol. u. Paläont. Abhandl.*, N.F., Bd. xv, Heft 4, 1927, 321–58, t. xxi.

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A Preliminary Note on the Buramo Schists, British Somaliland.

By John Parkinson, Sc.D.

DURING 1931 the writer had occasion to make several journeys across the western part of the coastal belt of British Somaliland, southward from Zeilah to Buramo, near the Abyssinian frontier.

The hilly, even mountainous district which succeeds the alluvial flats may be called, from the dominant race inhabiting it, the Gadabursi country.

Between 60 and 70 miles south of Zeilah crystalline rocks of very varied age and type make their appearance and continue, overlain here and there by outliers of Jurassic beds, across the International Frontier. Amongst these a group of hornblende-schists with variable content of black mica, passing into massive epidiorites and veined by a non-porphyritic, fine-grained gneiss or granite of aplitic composition, is conspicuous, and was termed for field purposes the Buramo Schists. As seen, macroscopic garnets are rare, nor did they usually appear in the heavy mineral residues taken from the sands of the tugs or drainage channels.

Work with the microscope being impracticable at the moment, a general description, without the advantage of thin sections, is all that can be attempted.

The hornblende-schists are included in the "hornblendic gneiss" of Farquharson (*First Report on the Geology and Mineral Resources of British Somaliland*, London, 1924, 9).

Exposures are very numerous, especially around the station of Buramo, to the north-east towards the Nadi Tug, to the north-north-west to Abassa, and in the Abassa Dadera Tug, while around the top of the Iswadli Pass, some 30 miles north-north-east of Buramo on the track to Buk Gego, magnificent sections of *lit par lit* structure are conspicuous, the black and white bands standing out clearly from afar.

The total area so included is about 800 square miles, how much greater is not known, but judging from Farquharson's report these rocks are extensively developed beyond the Gadabursi country.

Around Buramo (more properly spelt Borimeh) the strike of the planes of foliation, which are typically vertical, varies but little from the north and south direction. Intense crush resulting from pre-Jurassic movement is always evident and has affected, not only the Buramo Schists, but all the other crystalline rocks, largely reconstructed sediments, examined.

In the hornblendic rocks, mica, chlorite, and epidote have been developed.

Brecciation of the basic part of the complex by the acid magma is seen in the tug bank at Abassa Dadera, in the Dumuk Tug near Buramo, and on the Nadi Tug, but generally not conspicuous, and when found, not on a large scale. Sections between Buramo and Nadi show that the basic part of the complex underwent, at least locally, differentiation followed by brecciation and streaking as indicated by the intermingling of various lithological types of differing degrees of basicity, and without the introduction of the acid magma. The whole recalls "The Differentiation Series" of the Channel Isles, even to such minor episodes in the history as the occurrence of thin veins of compact felspar containing large elongated hornblende crystals and fine-grained rocks composed almost entirely of the latter mineral. The acid element, often very subordinate, is predominant in the hill immediately west of Buramo station (with occasional thin bands of crushed mica-schist); between Buramo and Harat, where over several miles of country patches of

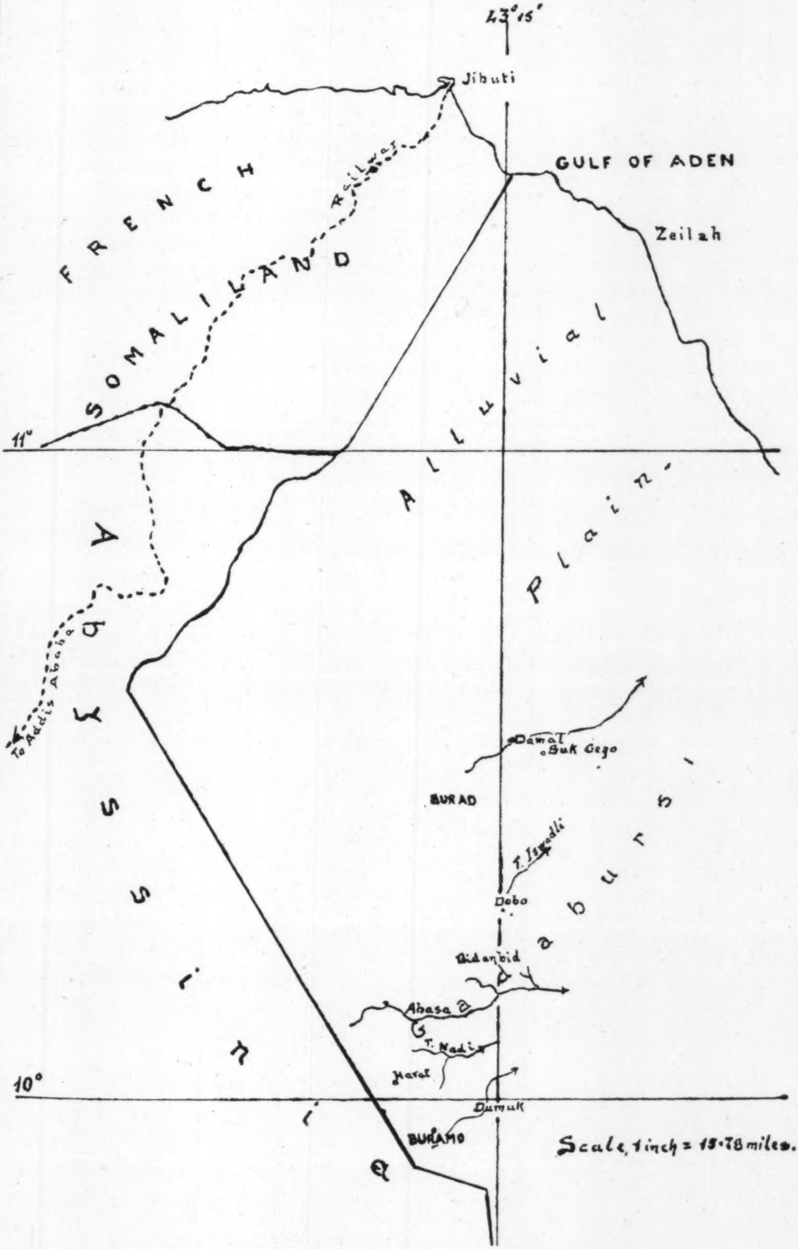
43°15'
Jibuti
GULF OF ADEN
Zeilah
FRENCH SOMALILAND
Railway
Alluvial Plain
11°
Abyssinia
To Addis Ababa
Damal
Buk Gego
BURAD
T. Isgadli
Dobo
Bidanbid
Abasa
T. Nadi
Harol
10°
Dumuk
BURAMO
Scale, 1 inch = 13·78 miles.

Fig. 1.—Sketch-map of part of British Somaliland.

hornblende-schist occur only rarely, and in the descent to Dobo from Bid an Bid.

The coarse, gabbroid, unfoliated condition of the basic part of the group is well exposed near Buramo, apparently occurring as haphazard lenticles in the schists. To what extent the foliation of the latter is an original structure is left for the microscope to determine, but that an east and west pressure emphasized an already strongly marked fissility and produced belts of shear is obvious.

In the field, the writer was of the opinion that fluxion during consolidation was responsible for the initial foliation and minor banding, while the massive rocks had occupied spaces surrounded by such zones of slow movement, and thus avoided the orientation of their constituents. It is also thought that these rocks, and to a large extent the acid gneisses, escaped the effects of much of the later intense pressure by the yielding of the structurally weaker schists.

In the writer's opinion the group is worthy of a distinctive name, not merely because of its wide distribution but because it may possibly form a basis or datum in relation to which the remaining rocks of a very complicated area can be eventually assigned.

The Petrography of Some Kainozoic Igneous Rocks, and of the Cape Parry Alkaline Complex, East Greenland.

By G. W. Tyrrell, A.R.C.Sc., D.Sc., F.G.S., F.R.S.E., Lecturer in Geology, University of Glasgow.

In this paper it is proposed to give a brief account of the petrography of the Kainozoic igneous rocks collected by Mr. J. M. Wordie during the Cambridge Expedition to East Greenland led by him in 1926.[1] A small collection of alkaline igneous rocks, but of less certain age, was also made from Cape Parry, and is briefly dealt with in this paper. As Mr. Wordie has written a short note on the geology of the Tertiary igneous rocks in his geographical paper, and as Dr. H. G. Backlund intends shortly to publish a much more comprehensive account of Tertiary igneous activity and rocks in East Greenland than is possible on the basis of the materials collected by the Cambridge Expedition, this paper aims only at making a brief record of the petrographical characters of the collection, and especially at recording three new chemical analyses, two of the Kainozoic basalts, and one of a riebeckite-trachyte from the Cape Parry alkaline complex. For the most recent account of the general geology of East Greenland, and for a connected summary of the Kainozoic igneous rocks collected by other expeditions, the reader is referred to memoirs by L. Koch[1] and H. G. Backlund.[2]

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[1] J. M. Wordie, "The Cambridge Expedition to East Greenland in 1926," *Geogr. Journ.*, Sept., 1927, 225–65, with map. Appendix V, "Geology," 252–3.

THE KAINOZOIC BASALTS AND ASSOCIATED ROCKS.

Mr. Wordie's collection includes lavas, sill and dike rocks, and volcanic tuffs. Mr. Wordie lays emphasis on the much more widespread distribution of intrusive sills compared with the occurrence of undoubted lavas. The preponderance of sills, for instance, is very marked on the east coast of Geographical Society Island, and they can be traced across Vega Sound into Traill Island. Lavas and sills are only named as such when the field evidence is definite.

A lava from Jackson Island, Gael Hamkes Bay (86)[3] is a fine-grained, intergranular, non-porphyritic basalt. The groundmass consists of plagioclase laths together with granules of pale augite, and comparatively sparse magnetite. The plagioclase varies much in size, from minute needles to elongated laths which may be regarded as of micro-porphyritic dimensions. The extinction is round about 30°, hence the composition of the plagioclase is Ab_1An_1. The augite, which is a practically colourless variety, occasionally reaches a microporphyritic size, and is then usually involved with the feldspar in small glomeroporphyritic groups. There are a few small pseudomorphs in green serpentine after olivine. Finally, a very small residue of brownish glass showing some obscure microlites may be recognized.

An analysis of this rock is given in Table I, 1, where it is compared with the analysis of a basalt from Scoresby Sound published by Professor A. Holmes. Both rocks are of the over-saturated basaltic type, and, on the whole, are of essentially similar chemical character. The new analysis specially conforms to that of the Scoresby Sound rock in its high lime together with low alkalies ; but since in the latter rock alumina is also high, the lime mostly enters anorthite, as is shown in the norm (Table II, 2), and the rock is decidedly feldspathic. In the described rock, however, alumina is relatively low, and the excess of lime enters diopside, which consequently appears in the norm in much greater quantity than in that of the Scoresby Sound rock. These differences are reflected in the A.Q.C. symbols relating to these rocks, the greater femicity of the Jackson Island basalt being indicated by the higher figure (III) in the first term of the symbol. The essential identity of the salic constituents in the two rocks, however, is reflected in the identity of the two

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[1] "The Geology of East Greenland: Stratigraphy of Greenland," *Medd. om Grönland,* lxxiii, 1929, pp. 1–320. "Tertiary Basalt," 186–200.

[2] "Contributions to the Geology of North-east Greenland," *Medd. om Grönland,* lxxiv, 1930, 209–96.

[3] The numbers in brackets are those attached to the rocks in the Cambridge Expedition collection. The localities mentioned can be found on the map in Mr. Wordie's paper already cited.

TABLE I.

	1	2	A	3	4	B	5	6
SiO_2 . .	48·64	46·84	47·8	43·20	42·57	46·73	64·82	75·14
Al_2O_3 . .	12·62	17·11	19·8	8·57	14·40	9·30	14·29	12·50
Fe_2O_3 . .	4·34	4·95	4·5	5·00	3·54	3·25	2·04	1·20
FeO . .	7·34	5·01	4·3	6·24	8·39	5·37	4·27	·87
MgO . .	7·33	5·72	5·0	12·00	6·78	14·93	1·00	·43
CaO . .	11·85	10·21	12·3	15·65	11·71	14·50	1·55	·83
Na_2O . .	1·85	1·61	2·4	1·30	2·70	1·32	5·62	3·00
K_2O . .	·31	·69	·3	·78	2·38	1·14	5·51	3·50
H_2O + .	1·05	2·53	1·4	2·40	2·05	·50	·20	Ign. 2·55
H_2O − .	2·25	1·63	·1	·80	·21	·45	·20	
TiO_2 . .	2·20	3·98	1·3	3·60	5·07	1·90	·33	·16
MnO . .	·12	·16	·2	·14	·10	·29	tr.	tr.
P_2O_5 . .	·18	·19	·3	·36	·12	·25	·13	—
CO_2 . .	tr.	none	·1	tr.	none	none	none	—
S . . .	none	·05	—	none	none	·04	none	—
(Ni, Co)O .	tr.	none	—	tr.	—	none	none	—
Cl . .	—	tr.	—	—	—	—	—	—
Cr_2O_3 .	—	? tr.	—	—	—	·15	—	—
V_2O_3 . .	—	·01	—	—	—	—	—	—
BaO . .	—	tr.	—	—	—	—	—	—
SrO . .	—	none	—	—	tr.	—	—	—
	100·08	100·69	99·8	100·04	99·98	100·12	99·96	100·18
		less 0·02						
		100·67						

1. Basalt lava (86), summit of Jackson Island, Gael Hamkes Bay, East Greenland. Anal. F. Herdsman, A.R.S.M.
2. Amygdaloidal basalt lava, south side of Scoresby Sound, East Greenland. Anal. H. F. Harwood. Quoted from A. Holmes, "The Basaltic Rocks of the Arctic Regions," *Min. Mag.*, xviii, 1918, 189.

A. Mean of the three basalt analyses of the "Porphyritic Central Magma-type" of Mull. Computed from analyses given in "Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban," *Mem. Geol. Surv. Scotland*, 1924, 24.

3. Ultrabasic, augite-rich olivine-basalt (ankaramite or monchiquite) (74), sill, Ladder Mountain, south-east of head of Muskox Fjord, East Greenland. Anal. F. Herdsman.
4. Melanocratic olivine-trachybasalt or feldspathic augitite (Holmes), lava, Hare Island, West Greenland. Anal. H. F. Harwood. Quoted from A. Holmes, op. cit. supra, 187.

B. Ankaramite, Hope Bay, Jan Mayen. Anal. W. H. Herdsman. Quoted from G. W. Tyrrell, "Petrography of Jan Mayen," *Trans. Roy. Soc. Edin.*, liv, pt. iii, 1926, 757.

5. Spherulitic riebeckite-trachyte, cobble from beach, Cape Parry, Traill Island, East Greenland. Anal. F. Herdsman.
6. Quartz-orthoclase-porphyry, dike, Cape Fletcher, Canning Land, East Greenland. Anal. N. Sahlbom. Quoted from O. Nordenskjöld, "On the Geology and Physical Geography of East Greenland," *Medd. om Grönland*, 28, 1909, 199.

following symbols for order and range (see Table II, 1, 2). It may be surmised that these two basalts represent magmas belonging to a simple, probably gravitational, differentiation series, of which the

" porphyritic central magma-type " of Mull is a still more extreme term in the salic direction (Table I, A and Table II, A).

Table II.

	1	2	A.	3	4	B.	5	6
Quartz	4·9	7·4	2·1	—	—	—	6·2	41·9
Orthoclase	1·7	3·9	1·7	4·4	13·9	6·7	32·8	20·6
Albite	15·7	13·6	20·4	5·5	3·5	6·8	42·4	25·2
Anorthite	25·3	37·5	42·3	15·3	19·7	16·1	—	4·2
Nepheline	—	—	—	3·0	10·6	2·3	—	—
Corundum	—	—	—	—	—	—	—	2·3
Acmite	—	—	—	—	—	—	4·2	—
Diopside	26·3	10·2	13·6	46·5	29·9	42·9	5·9	—
Hypersthene	12·0	9·6	8·6	—	—	—	6·2	1·5
Olivine	—	—	—	7·1	5·0	15·3	—	—
Magnetite	6·3	4·6	6·5	7·2	5·1	4·6	·9	1·9
Ilmenite	4·3	7·6	2·4	6·8	9·7	3·7	·6	·3
Haematite	—	1·8	—	—	—	—	—	—
Apatite	·3	·3	·6	1·0	·3	·5	·3	—
Chromite	—	—	—	—	—	·15	—	—
Silica Number	82	123	35	– 91	– 189	– 138	103	698

These norms are arranged in the same order as the analyses in Table I. The symbols of the analyses in the American Quantitative Classification are :

1	III	(4) 5	4	″5
2	II (III)	(4) 5	4	4
A	II″	Q 5	4	″5
3	IV	5 (6)	(3) 4	″4
4	III	6	3	(3) 4
B	″IV	5″	(3) 4	(3) 4
5	″II	″5	1	3″
6	I	3	(1) 2	3″

Successive lava flows at 400-ft. and 450-ft. levels on the southern slopes of the Stufenberg, Pendulum Island (36, 37), are amygdaloidal basalts with an abundant dark glassy base which encloses aggregates of colourless granules of augite and lathy plagioclases, producing an intersertal texture clearly comparable to that of the Brunton type of tholeiite.[1]

A trachybasalt comparable with the Dunsapie type of the Scottish Carboniferous [2] occurs about three miles inland from the coast at Mackenzie Bay, on the Hold With Hope peninsula (81 D). It carries a few large phenocrysts of pale purplish augite and serpentinized olivine, with numerous smaller phenocrysts of albitized, and in some cases analcitized, labradorite, in a fine-grained intergranular groundmass consisting of altered plagioclase laths, granules of augite and titaniferous iron ores, with numerous flakes of red-brown biotite which are specially prominent on the edges of the steam cavities. Some of the vesicles are filled with fresh analcite. This rock has clear affinities with the mugearites as well as with the olivine-basalts of Dunsapie type.

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[1] " Tertiary and Post-Tertiary Geology of Mull," *Mem. Geol. Surv. Scotland,* 1924, 372 ; and fig. 62B, 371.

[2] A. G. MacGregor, " The Classification of Scottish Carboniferous Olivine-basalts and Mugearites," *Trans. Geol. Soc. Glasgow,* xviii, pt. ii, 1928, 324–60.

The other analysed basaltic rock collected from the summit (3,150 feet) of Ladder Mountain, south-east of the head of Muskox Fjord (74), is of a quite different type to that of Jackson Island, and Mr. Wordie states that this rock probably comes from a sill. In thin section it shows numerous, large, euhedral phenocrysts of very pale purplish augite, the colour of which deepens towards the margins of the crystals, with fewer phenocrysts of fresh or only partially serpentinized olivine, embedded in a groundmass which consists predominantly of granules of augite and iron ores. The remainder of the groundmass consists of a pervading, low-polarizing base, in which a few laths of plagioclase (? labradorite) may be identified. The rest probably consists of orthoclase and nepheline which cannot, however, be certainly identified, although indicated as present by the chemical analysis. Some irregular steam cavities are filled by a radiating zeolite of low birefringence, which has been identified by Mr. J. D. H. Wiseman as heulandite. The principal feature of the rock is the predominance of augite, from which, combined with the retrogression of olivine and plagioclase, it may be identified as an ultrabasic, augite-rich, olivine-basalt, or ankaramite (Lacroix). It is very closely allied to monchiquite, which it would be styled by some petrologists owing to its probable intrusive mode of occurrence.

This diagnosis seems confirmed by the results of the chemical analysis (Table I, 3) with its low alumina and silica, very high lime and only less high magnesia, combined with relatively low alkalies in which potash is relatively prominent. The analysis compares well with that of an ankaramite, thought to be a sill from the Pleistocene volcano of Jan Mayen (Table I, B), which shows the same general features, especially the relatively high potash. No other Greenland rock of like composition has been analysed so far as is known, but the melanocratic olivine-trachybasalt or feldspathic augitite from Hare Island, West Greenland, described by Professor A. Holmes and analysed by Dr. H. F. Harwood (Table I, 4), is clearly a member of the same magma-series, but much richer in feldspar and nepheline. The norms of these three rocks are displayed in Table II, 3, B, 4). They all represent thoroughly undersaturated types in which a small amount of nepheline appears along with relatively sparse olivine, but a large amount of diopside. Their complete difference from the oversaturated types is shown by the difference in the A.Q.C. symbols, the class symbols indicating greater femicity, and the order and rang symbols greater alkalinity, for the undersaturated types. The subrang symbols likewise indicate the more potassic composition of these types. The trachybasalts of Jan Mayen and Iceland, and the plateau-magma type of Mull, belong to the same magma-series, but towards its feldspathic end.

In addition to the ankaramite or monchiquite of Ladder Mountain, three other rocks in the Cambridge collection are described by Mr. Wordie as collected from undoubted sills. One of these (21) which comes from Walrus Island, just south of Sabine Island, is a beautifully fresh, fine-grained, olivine-essexite or essexite-dolerite. It shows numerous large crystals of fresh olivine and purple titanaugite, often forming small glomeroporphyritic groups, in a coarsely-intergranular groundmass consisting of laths of labradorite, granular augite, and plentiful flakes of red-brown biotite which is often involved with, or is an outgrowth from, large euhedral grains of iron ore, apparently magnetite. Alkali-feldspar and probably nepheline, in small amount, occur in the groundmass, but an isotropic material which is almost certainly analcite pervades the whole rock. It is, however, more heavily concentrated in spots, around and within which the feldspars have been largely replaced, and in which large crystals and needles of apatite are also more abundant than in the rest of the rock. The nearest analogue of this rock in the Scottish Kainozoic field is the crinanite of the sills of Arran,[1] which is, however, of coarser texture, poor in alkali-feldspar, and, as a rule, devoid of biotite. The Greenland rock has even closer affinities with the Permo-Carboniferous essexites of the West of Scotland.[2] It may be regarded as the hypabyssal representative of the magma whence the above-described trachybasalt was derived.

A sill rock also occurs at the summit of the Hasenberg on Sabine Island (28). It is as fresh as the above-described essexite-dolerite, but of entirely different petrographical character. The essexite certainly belongs to the undersaturated group, and just as certainly the Hasenberg rock must be assigned to the oversaturated group. It consists of a holocrystalline intergranular complex of laths of labradorite, granules of pale augite, and iron ores, in which are interspersed little glomeroporphyritic aggregates of labradorite and augite, and a few scattered microphenocrysts of serpentinized olivine. It exactly resembles the holocrystalline varieties of olivine-tholeiite of Salen type from Mull.[3]

Another sill comes from Sabine Island, about two miles south of Cape Neumayer (25). It is a coarse-grained, ophitic olivine-dolerite of uncertain affinities. The augite is of a pale purplish colour, and the olivine has been largely transformed into a bright, brownish-yellow, fibrous serpentine. This rock closely resembles certain olivine-dolerites of the crinanite affiliation in Western Scotland, which are nevertheless free from zeolites.[4]

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[1] G. W. Tyrrell, "The Geology of Arran," *Mem. Geol. Surv. Scotland*, 1928, 118.

[2] G. W. Tyrrell, GEOL. MAG., 1912, 120.

[3] "Tertiary and Post-Tertiary Geology of Mull," *Mem. Geol. Surv. Scotland*, 1924, 370.

[4] G. W. Tyrrell, "Classification and Age of the Analcite-bearing Igneous Rocks of Scotland," GEOL. MAG., LX, 1923, 251.

Both Nathorst and Koch have mentioned the occurrence of acid eruptives and tuffs at Cape Broer Ruys, at the south-eastern corner of Hold With Hope, and at Cape Franklin on Gauss Peninsula at the southern end of the Giesecké Mountains. These occurrences are taken as indications of the former existence of central volcanoes presumably like those of Skye, Mull, Ardnamurchan, and Arran. It is interesting to find these views supported by specimens collected by Mr. Wordie and his colleagues at Cape Broer Ruys, Cape Franklin, and Cape Bennet.

A specimen from 2,000 feet height on the mountain at Cape Franklin, Foster Bay (81 A) proves to be an unmistakable rhyolite-tuff, containing mostly angular fragments of dense, cryptocrystalline, or felsitic textures, some with a vague banding or flow structure and numerous fragments of quartz, in a dense, grey, cryptocrystalline matrix.

From Cape Bennet, Mackenzie Bay (81 B) comes a fine-grained quartz-dolerite with the acicular mode of crystallization and the acid mesostatis characteristic of the basic members of the craignurite series of Mull.[1] From inland about three miles north-east of Mackenzie Bay, was collected a very fine-grained rock of the same type (81 C) which almost certainly represents a chilled marginal facies of a quartz-dolerite intrusion. The acid or felsitic end of the craignurite series is represented by a specimen from a dike on the south side of Cape Broer Ruys (82), which, however, contains a few glomeroporphyritic groups of fresh labradorite, a feature which appears in some of the more acid members of the craignurite series of Mull.[2]

THE ALKALINE IGNEOUS COMPLEX FROM CAPE PARRY, TRAILL ISLAND.

On Traill Island, and on the adjacent eastern coast of Scoresby Land, across Davy Sound, there occur numerous intrusions of alkaline igneous rocks, which have been mentioned and described by A. G. Nathorst,[3] O. Nordenskjöld,[4] L. Koch,[5] and J. M. Wordie.[6]

Nathorst's collection from Cape Parry included aegirine-quartz-syenite, and tinguaite or solvsbergite, with a monchiquite from the Fame Islands. Nordenskjöld's collection from Cape Fletcher, Canning Peninsula, included syenites, orthoclase-porphyries, ultra-basic lamprophyres (alnöites, etc.), and dikes of nepheline-tephrite. In an account of the " Cape Fletcher Series " Koch mentions alkali-syenites (Antarctic Harbour), and various diabases ; and from Cape Simpson on Traill Island a small collection included rocks determined as ekerite or alkali-granite, granite-porphyry, syenite-porphyry, and quartz-porphyry.

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[1] " Tertiary and Post-Tertiary Geology of Mull," *Mem. Geol. Surv. Scotland*, 1924, 225.

[2] Ibid., 227.

[3] " Bidrag til Nordöstra Grönlands Geologi," *Geol. För. Förh. Stockholm*, 23, 1901.

[4] " On the Geology and Physical Geography of East-Greenland," *Medd. om Grönland*, xxviii, 1907, 151–284. For alkaline rocks see pp. 195–214.

[5] " Geology of East Greenland," *Medd. om Grönland*, lxxiii, 1929, 119–24.

[6] " The Cambridge Expedition to Greenland in 1926," *Geogr. Journ.*, Sept., 1927, 225–65. " Geology," 252–3.

Of the Cambridge Expedition collection at Cape Parry aegirine-riebeckite-granite (90), quartz-aegirine-riebeckite-syenite (89), syenite-porphyry (92), soda-felsite (91), quartz-orthoclase-porphyry (87), and an acid tuff or igneous breccia (88), were found in situ. Pebbles collected from the beach included aegirine-granite (93), quartz-riebeckite-syenite-porphyry (94), and a spherulitic riebeckite-trachyte or perhaps solvsbergite (95). A further detailed description of these rocks and of their interesting and rich minerals will, it is hoped, be undertaken, and the present is merely a preliminary note.

The last-named rock (95) has been analysed by Mr. F. Herdsman, with the result set out in Table I, 5. The norm shows 6·2 per cent. of quartz, and 4·2 per cent. of the acmite molecule (Table II, 5). The analysis agrees closely with that of the trachyte of the plug and sill in the Kainozoic vent of Bráigh a'Choire Mhóir in Mull,[1] which also contains a soda-amphibole allied to riebeckite, as well as some aegirine-augite.

The only other published analysis of a rock comparable with those from the Cape Parry alkaline complex is that of a quartz-orthoclase-porphyry dike from Cape Fletcher, Canning Peninsula (Table I, 6) which, from Nordenskjöld's description (see reference quoted in Table I), seems to be closely similar to the quartz-orthoclase porphyry (87) from Cape Parry. The analysis agrees fairly well with that of the quartz-feldspar-porphyry from Bennan, Arran.[2]

The age of these alkaline rocks is still open to question. Koch records " pebbles of the Cape Fletcher porphyries " embedded in fossiliferous strata which have been referred to the lowermost Permian,[3] and therefore assigns this igneous episode to the interval between Carboniferous and Permian. More information as to the petrological nature of these porphyry pebbles should be forthcoming before this age can be accepted. There may be more than one alkali series, and on present evidence a Tertiary age for the Cape Parry rocks seems not unlikely.

ACKNOWLEDGMENTS.

The cost of the two new basalt analyses published in this paper has been defrayed from a grant made by the Government Grant Committee of the Royal Society. I am also much indebted to Mr. Wordie for a careful revision of the geological references and place-names.

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[1] " The Tertiary and Post-Tertiary Geology of Mull," *Mem. Geol. Surv. Scotland*, 1924, 191–2.

[2] G. W. Tyrrell, " The Geology of Arran," *Mem. Geol. Surv. Scotland*, 1928, 204.

[3] Op. cit., 124. Also personal communication from H. G. Backlund.